FLOOD FLOWS, A COMPARISON OF VARIOUS METHODS OF ANALYSIS AS APPLIED TO RIVERS OF THE SOUTHEASTERN UNITED STATES.

A Thesis

Submitted for the Degree of

CIVIL ENGINEER

By

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B. S. in C. E., 1929

Georgia School of Technology

Date May 16, 1935

Approved by

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FOREWORD

Within the past four decades the science of the analysis of flood frequencies and magnitudes, and its application to engineering problems may be said to have had its inception; during the past twenty-five years most of the principles currently used in practice were formulated. Much study has been given to the analysis of flood records, and considerable literature has been published on the subject.

Numerous methods for estimating probable floods of a stream have been proposed and used: individual methods requiring basic data ranging from a complete record of discharge for a number of years at the flood station, for the statistical methods, to merely a knowledge of the size of the drainage area and length of the stream, for the more approximate empirical formulas.

In the words of the late Allen Hazen,

> "The collection of (flood) data in the United States has gone faster in the last decades than the analysis of the results, but there has been progress in this also, and a number of valuable papers have been published that have been and are of great assistance in this study."

This paper assembles under one cover a number of methods of flood analysis in current usage, reviews briefly the theory involved in each, illustrates the application of each to specific problems, and attempts to define the relative value of the different angles of approach to the problem of estimating flood probabilities; each method of analysis is applied to a group of streams in the southeastern United States, and a comparison of results obtained; a discussion of the significance of the results and of the limitations of different methods of analysis is made; and conclusions are drawn as to the probable value of various methods of analysis as applied to problems of engineering practice.

Acknowledgment is made to the United States Engineer Office, Savannah, Georgia, for permission to use the photographs contained in this paper, and for access to its files of flow data on some of the rivers included in this study. A bibliography of authors and works consulted is given in Appendix I.

INTRODUCTION

Since the beginning of the twentieth century, considerable attention has been focussed on the problem of flood damage prevention in the United States at large. Prior to that time, study of this problem was limited to a few of the very large rivers of this country.

This new interest may be partially accounted for by the increasing value of lands in the vicinity of population centers; where such centers are located on streams, as frequently occurs, industrial developments, dwellings, and other works of man, are often induced to occupy lowlands which are in reality the flood plain of the river in question. Many years may elapse without such areas being inundated; but, experience has shown, eventually those marginal areas, those encroachments on the river's right-of-way, so to speak, unless artificially protected will be subjected to flooding, and sometime with devaztating effect. Again, in the early days (and in more recent times also, for that matter) of railroads and highways, the provision of insufficient bridge clearances and water openings led to the destruction of many such bridges in time of flood.

Thus, on the whole, there has been considerable incentive for human organization to cope with the problem of the river in flood. Communities, where subjected to inundation, have looked about them for methods of protection; designers of hydraulic structures have attempted to provide sufficient water discharging capacity for safety during the life of the works. In many individual cases, it has been demonstrated that it is possible to develop dependable and very accurate methods of flood prediction based on recorded rainfall and size of drainage area. In such cases the United States Weather Bureau, in cooperation with local city authorities, has given affected communities twenty-four or

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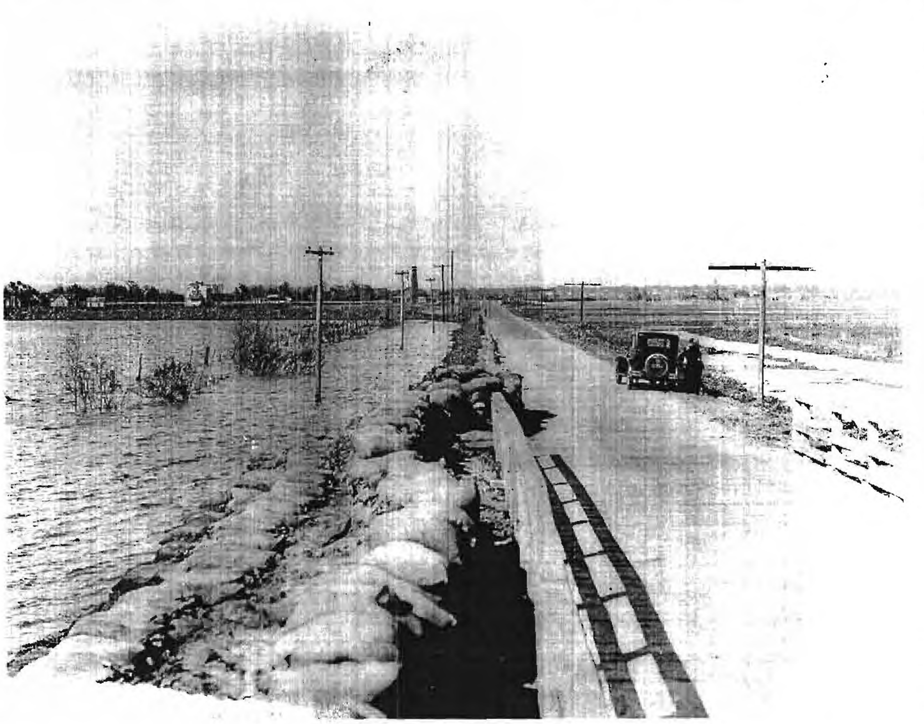
Atlantic Coastal Highway, near South Newport River, Ga., March 16, 1929.



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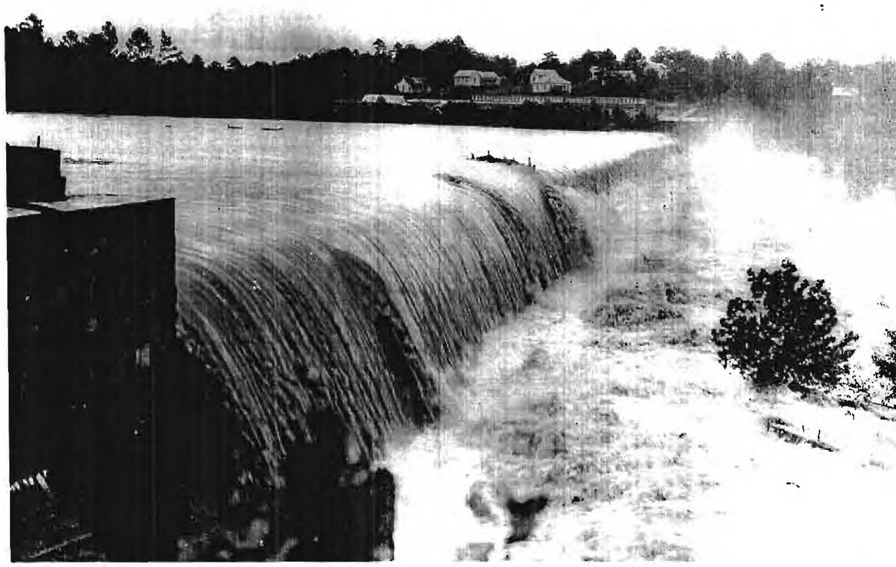
SOME RIVERS IN FLOOD



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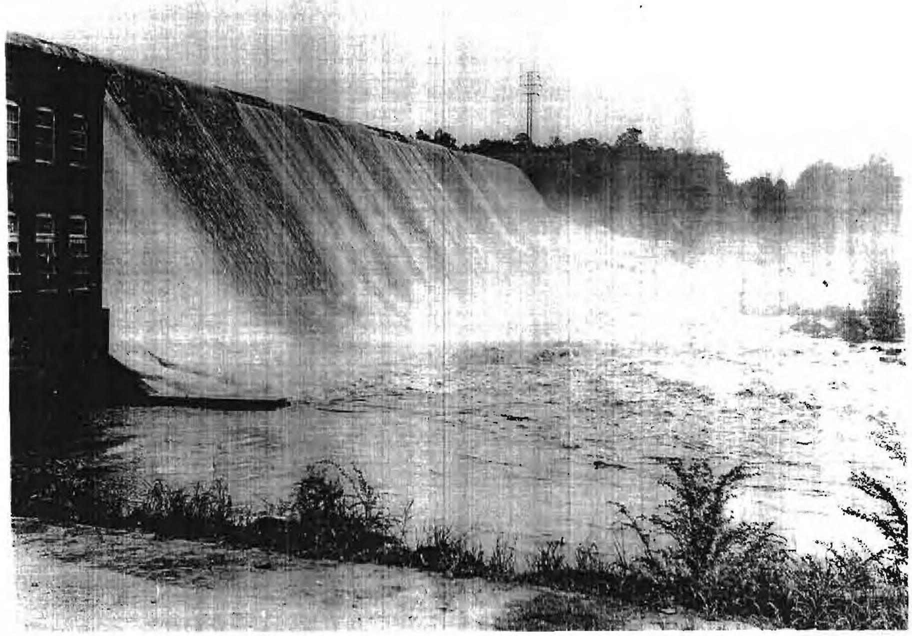
Ocmulgee River at Juliette Dam; October 5, 1928.



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Ocmulgee River at Jackson Dam; October 6, 1928.

OCMULGEE RIVER IN FRESHET

more hours' notice of impending major floods, which has allowed some limited preparation, with consequent saving of life and property. If such flood prediction methods were developed for all communities having a flood problem, much loss of life and property could be avoided at small expense.

In all engineering works pertaining to the use of, storage of, or protection from the waters of a stream, a fundamental question upon which ultimate success of the project depends is the maximum rate of discharge for which provision is to be made. An attempt to arrive at the value of this discharge in turn leads to a study of past experience as a basis for estimating future probable discharges.

As a basis for such studies, there are in existence, records of river discharge and gage heights for varying lengths of period at strategic points on numerous streams of the country. These records are, at best, too short, the longest complete ones covering about eighty years, with some broken periods of more than a century. The United States Geological Survey has done a very laudable work in recording, compiling, and publishing such records, its series of Water Supply Papers being by far the most comprehensive records of streams available in this country; these records of former years, are being constantly enlarged by compilation of many individual records made by private power companies and other interested individuals. Rainfall records, made by the United States Weather Bureau are available in a much more complete degree, and may be of great value in estimating the flood discharge of a stream; indeed, because of the relative completeness of rainfall records, flood formulas have been devised, based solely on rainfall probabilities and physical characteristics of the drainage area.

In the past three decades, much progress has been made in the analysis of the flood data that is available. This paper presents no new method of analysis; it reviews and attempts to evaluate a number of methods of analysing and plotting flood data, previously developed, as applied to the rivers of the southeastern United States. Ten stations on as many streams in the area under study are selected. The record of each is subjected to several methods of analysis, the results are compared, and a discussion of the interpretation and significance of the results is made. Conclusions are drawn as to the usefulness and limitations of the methods considered.

METHODS OF ANALYSIS

1. General. Several recognized methods of analysis, based on statistical arrays at the specific location in question, and requiring recorded data , in varying degrees of completeness, are in current usage. Unfortunately, it is frequently necessary to estimate the probable flood discharge of a stream where the flood record is very meager, or perhaps no data at all is available. To assist in such an estimate, approximate formulas based on rainfall and physical characteristics of the drainage area have been developed.

For convenience, the different methods studied in this paper may be broadly grouped according to the basic data required, into Statistical Methods, and methods employing approximate flood formulas. The Statistical Methods may be further classified as Time Series Methods and Basic-Stage or Partial Series Methods. Listed under the above classifications, in this paper the following methods of analyses and of estimating probable floods are studied:

I. Statistical Methods.

a. Equal Time Series

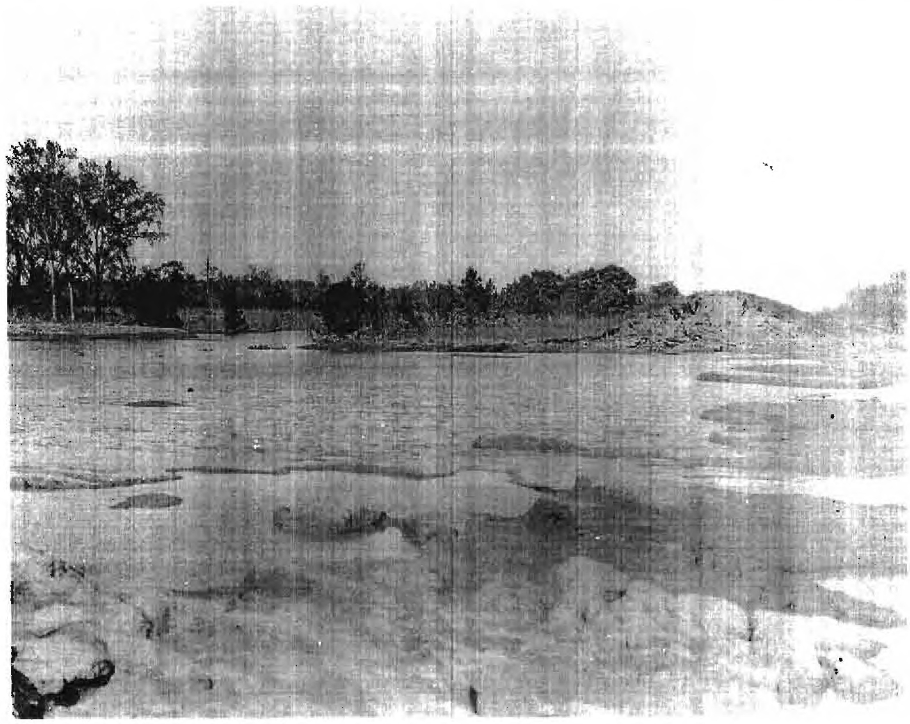
(1) The Annual Flood Method.

(2) The Goodrich Method of Straight Line Plotting of Skew Frequency Data.

(3) The Monthly Flood Method. In this paper, this method is not treated as a complete series, only the flows above a given stage being used, for brevity.

(4) The Daily Flow Duration Method, as in (3) above. This method is not treated as a complete time series, only the flows above a given stage being used.

b. Basic-Stage Methods



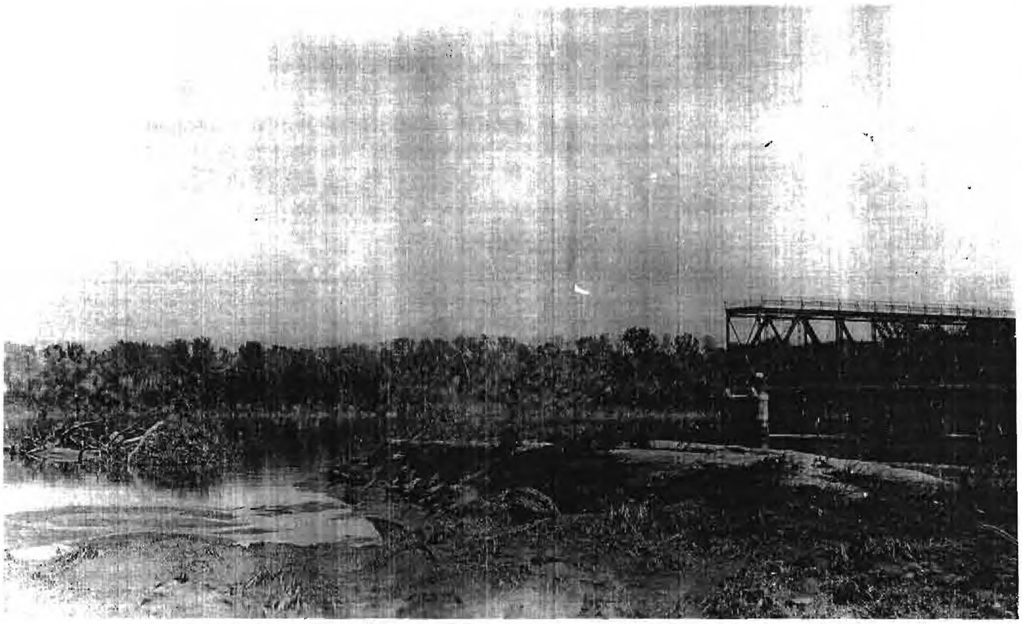
U. S. Engineer Dept.

Break in Augusta City Levee, 8 miles below the city, Oct., 1929.

U. S. Engineer Dept.

Break in trestle approach to Charleston and Western Carolina Railway bridge over Savannah River, 4 miles below Augusta, Ga., October, 1929.

SOME DESTRUCTIVE EFFECTS OF FLOODS.



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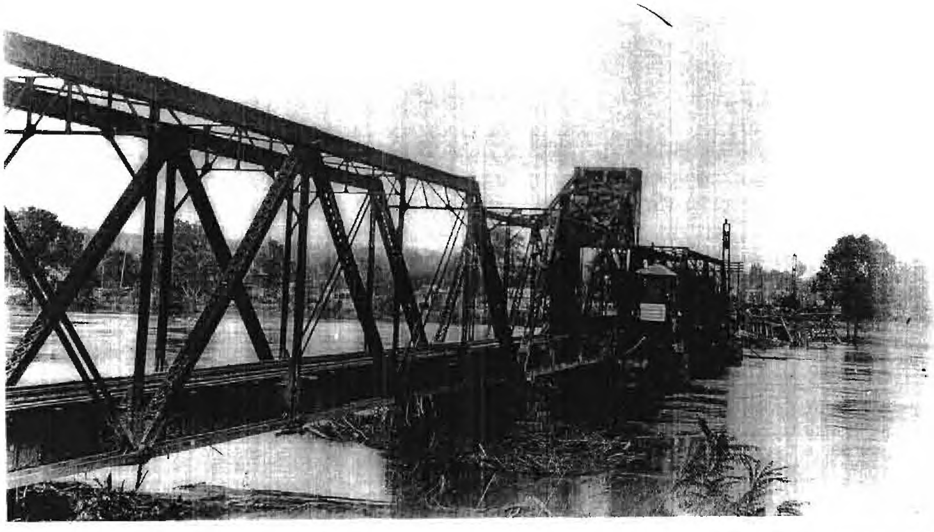
Sandbar Ferry Highway bridge over Savannah River, four miles below Augusta, Ga. October, 1929.



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Southern Railway Bridge over Savannah River at Augusta, Ga., October, 1929; note destroyed span in background.

SOME DESTRUCTIVE EFFECTS OF FLOODS (Contd.)

(1) The Flood Event, or Partial Series Method.

(2) The Average Number of Floods per Century, or Modified California Method.

Methods (3) and (4) under "a" above are in reality treated as Basic-Stage Methods, because of the much shorter time required to analyse them by this method than by a similar analysis as an equal time series, due to the extremely large number of terms.

II. Approximate Flood Formulas.

(1) The Fuller Formula.

(2) The Pettis Formula.

A discussion of the use and limitation of each of these methods is given below.

2. Definition of Terms. For this study the following names have been applied to flood quantities:

The Maximum Annual Flood is the greatest rate of flow at any minute during any one year.

The Annual One-Day Flood is the greatest average rate of flow in one record day within the record year.

The Average Maximum Flood is the average of the maximum annual floods for a series of years, one for each year.

The Average One-Day Flood is the average of the annual one-day floods for the record period, one for each year. This value will be used as a basis for estimating other floods in the Annual Flood Method, and will be referred to, for simplicity, as the average flood.

The Ten Per Cent Chance Flood used in the Annual Flood Method is that flow such that it will probably be exceeded on an average, in ten per cent of the whole number of years. That is, the limit will be exceeded once in ten years or ten times in a century. The term

10-year flood is used synonomously with the ten per cent chance flood in this paper. In a similar manner, other chance floods are referred to, for example, the 20 per cent chance or 5-year flood, and the one per cent chance or 100-year flood.

In connection with theoretical frequency curves, the following terms are used.

Skew Curves are curves that are not symmetrical. Data relating to flood flows diverge systematically from the normal law of error and produce skew curves. Among the characteristics of flood flow data when arranged in a series are: more than half the terms are below the mean, and the largest term exceeds the mean by a larger amount than the smallest term falls short of it.

The Coefficient of Variation is an index of the relative amount of variation from the mean in any series of figures. That is, the coefficient of variation of any series of numbers is a measure of the degree of dispersion of those numbers. The variation of a term in a series is the amount by which it differs from the mean. The Standard Variation is the square root of the sum of the squares of the variations of the terms of a series divided by the number of terms minus one. The coefficient of variation is the ratio of the standard variation to the mean of the series. In this paper, such series are expressed in terms of the mean so that the standard variation and the coefficient of variation become the same.

The Coefficient of Skew is an index of the curvature, or lack of symmetry of a series. It is the sum of the cubes of the variations of the terms of the series divided by the number of terms less one and the quotient divided by the cube of the standard variation.

3. <u>Statistical Methods</u>. All of the methods of flood flow investigation by statistical processes included in this study call for extrapolation of duration or cumulative frequency curves based on available records of flow.

According to the law of probabilities, the probable percentage of future floods that will equal or exceed a given magnitude is given by the following equation:

$$p = \frac{100\,(m - 0.5g)}{n}$$

where $p =$ the probable percentage of future floods that will equal or exceed a given flood, expressed as a whole number;

$m =$ the number of times, during the period of record that the given flood was equaled or exceeded;

$n =$ the total number of items that occurred during the period of record;

$g =$ number of floods of the given size that occurred during the period of record, when all of the floods of a given size are grouped for convenience in plotting; when the data are not grouped (e.g., the annual flood method), $g = 1$.

This obviously plots each point at the mid-interval of its class. The reason for this plotting may be best explained by an example. In a given 20-year record of annual floods, the maximum value in the record represents the highest discharge of a period covering 5 per cent of that record. If an annual flood record of 100 years were available at this station, the highest 5 terms would represent the highest 5 per cent of time on the graph of this cumulative frequency curve. Some of these would be greater and some would be smaller than the highest value in the original 20-year record. Based on the "theory of sampling," the highest value in the original 20-year record is taken to be the average or representative value of the class of floods which prevailed over the highest 5 per cent of the time in the hypothetical 100-year or other long term record. Therefore, to be plotted as representative of a class or group, it should be plotted at the mid-interval of its group, in this case at $2\frac{1}{2}$ per cent of the time.

All of the statistical methods are based on the so-called theory of sampling; this assumes that the available record constitutes a representative sample of a long-term (five hundred or one thousand year) record of the same stream; that is, if we have an available record of a stream for thirty years, and from the hypothetical 1000-year record of the same stream select at random sufficient items to represent a period of thirty years; if a number of such 30-year hypothetical records are picked at random, it is assumed that the average of these would approximate the actually available 30-year record.

It is evident that the length of available record is the all-important factor in an analysis based on the above assumptions; the nearer the actual record approaches the hypothetical long term record, the more dependable will be the results of the analysis; the more liklihood that we have a representative sample of the flow of an individual stream. At the present time, records of 20 years in length are considered as a minimum usable, and 30 or 40 years is much more desirable. In this paper one record of 19 years is used, while the average length of all the records studied is 35 years.

In the past certain engineers have made too free a use of extension of frequency curves, going so far as to predict the 1000 or even 10,000 year probable flood magnitude, based on a 25 or 30 year record. This practice has led some engineers to condemn all use of frequency curves. However, it is believed that within reasonable limits the method is absolutely sound. At any rate, statistical methods are the most dependable ways of estimating flood flow frequencies now in use. In this paper, the 100 year probable flood is the greatest which an attempt is made to determine, this requiring only a moderate extension of the curve beyond the record data.

4. Probability Plotting Paper. Whenever applicable in this study, probability paper, designed by Messrs. Hazen, Whipple, and Fuller, is used to facilitate drawing of curves. The late Mr. Allen Hazen described this paper as follows:

> "The spacing of the (abscissae) lines for this paper was computed from figures taken from probability curve tables, and arranged so that the line which represents the summation of the probability curve, when plotted on it, is straight. If the data for any series correspond strictly with the normal law of error, the points plotted on this paper will all be on a straight line. If the data approximate the normal law of error, the line through the points will approximate a straight line. Even though the deviation from the normal law of error is considerable, a line with only a moderate curvature will represent it fairly well." 1

Mr. Hazen further described probability paper with arithmetic and logarithmic ordinate scales as follows:

> "It was soon found that many kinds of data when plotted upon arithmetic probability paper fell in lines with considerable curvature, and this led to an effort to find some form of plotting that would permit such data to be shown with less curvature. One of these methods tried was to substitute a logarithmic scale for the arithmetic scale, the probability scale remaining unchanged. * * * It was soon found that paper of this description was better than arithmetic probability paper for many uses, among them the plotting of flood flows. * * * Logarithmic probability paper is printed in two forms; one extending to the 0.01 per cent limit in each direction, and suitable for general use, and a special form extending to the extreme values at one end, with a corresponding shortening at the other which is adapted to plotting series with more than five thousand terms, and for estimating extreme values near one limit." 2

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1. Transactions, Am. Soc. C. E., Vol. 77 (1914) p. 1549

2. "Flood Flows," Allen Hazen, 1930.

The extreme probability paper described above is used in this paper for plotting results of the Flow Duration Method of analysis, while the logarithmic probability paper is used for plotting results of a number of the other methods.

In 1926, Mr. R. D. Goodrich presented a special method of plotting skew frequency data, so as to give a straight line. This is treated as a method of analysis and is described under a separate paragraph below.

5. Approximate Formulas. Approximate flood prediction formulas have been developed by empirical means, which attempt to include factors depending on: (1) the physiography of the basin in question, and (2) those depending on the weather. Various forms of equations have been proposed, including exponential and logarithmic functions. The chief difficulty in the application of such formulas is the determination of constants intended to represent specific drainage areas, and variability of the weather. The great advantage of such formulas is that if a sound one is properly applied, an approximate value of probable floods may be obtained at stations where no records exist, and where otherwise no idea of flood magnitudes and frequencies could be gained.

6. Relation of Peak Flow to Average Daily Flow. Inasmuch as most available records are in terms of average daily flow, and in most cases the application of results of flood frequency studies require the peak or instantaneous rate of flow, some conversion factor between the two is essential. In this paper, the formula developed by Mr. Weston E. Fuller, as applicable to all of the United States approximately east of the Mississippi River will be used. This formula is:

$$Q\ (\text{max.}) = Q\ (\text{Ave.})(1 + 2A^{-0.3})$$ [3]

3. Transactions Am. Soc. C. E., Vol. 77 (1914)p. 567.

where Q = discharge,

and A = drainage area in square miles.

Until recently data on average daily and corresponding peak discharges were relatively scarce. With the greater use of automatic water stage recorders, however, a large number of such relations will become available. Mr. Fuller's formula, derived in 1913, with limited records, is probably subject to revision in the light of new data, but for this paper it is accepted as the best available.

7. The Annual Flood Method. The maximum daily flow in each year of the record is ascertained. These flows are then arranged in order of magnitude, and plotted as a cumulative frequency curve. Per cent of time for plotting is given by the formula:

$$p = \frac{100(m - 0.5)}{n}$$

where n = number of years in the record.

The flows may be plotted directly in cubic feet per second, or they may be plotted as ratios to the mean flood. The use of ratios has two advantages: (1) In making a general comparison of different streams it is necessary, and (2) In the individual case, by use of ratios, the coefficient of variation, and coefficient of skew may be found, and the coordinates of a smooth curve, through the actual record points, computed from skew curve tables, such as those prepared by Hazen or Foster. If the ratios are plotted, they may be converted back to cubic feet per second by multiplying them by the mean flood. In this paper, ratios are used.

To define a frequency curve, it is necessary to know its spread laterally from the mean (in other words, its standard variation), and its lack of symmetry (that is, its skewness). With this definition of the curve,[4] in the individual case, a series of factors may be taken from prepared tables, and a curve representing the actual record points computed and plotted. Mr. Foster in his paper, has computed by a rigorous mathematical procedure a series of factors to be used in determining plotting points for curves with given coefficient of variation and of skew. A number of types of skew curves are recognized, and Mr. Foster, following the classification of Karl Pearson, prepared tables for two of these types, called Type I and Type III. The late Allen Hazen, independently, and by a somewhat empirical method, developed a series of factors, referred to here as Logarithmic Probability Factors, which may be used in exactly the same way as those prepared by Foster. As to choice of factors to be used in the individual case, the one should be used which best fits the actual record points. When this criterion is applied, Type III is more suitable for flood data than Type I. As to the choice between Foster's Type III, and Hazen's Logarithmic Probability Factors, there is little difference in the results. Foster's factors are mathematically correct, and might be preferred for this reason, but the logarithmic factors, other things being equal, will produce slightly higher values for extreme positions, and thus is slightly more conservative. On any such curve, if the coefficient of skew is increased, it will increase the size of the terms at both ends and will decrease some of the middle terms, the adjustment being such that the average of the series and the coefficient of variation will not be changed. Decreasing the coefficient of skew will have

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4. The theoretical treatment of determining and plotting skew frequency curves is given in the paper on this subject by Mr. H. Alden Foster in Transactions Am. Soc. C. E., Vol. 87 (1924), p. 142 et seq. Only the detailed application of this method is given in this paper.

the reverse effect. In about one out of ten plottings, on an average, it will be found that the coefficient of skew does not give a curve best representing the record points. In such cases, several plottings may be made with higher or lower assumed values of the coefficient of skew, and the one which appears to best fit the record points should be retained. This coefficient thus determined is called the graphic coefficient of skew. Hazen says:

> "Wherever a graphic coefficient of skew is found that fits the data better, it is substituted for the calculated coefficient of skew * * * . The graphic procedure is trumps in this game, and no method of calculation stands where the graphic procedure better accounts for the facts."

The 10 year, 100 year, etc., annual flood is that record day average rate of flow which is predicted to fulfill two conditions: (1) it will be a maximum for the record year, and (2) it will be exceeded once in 10, 100, etc., years respectively. Since these conditions must be satisfied simultaneously, the 10, 100, etc., year annual flood is not the record day flood that is likely to be exceeded once in 10 or 100 years, but is considerably smaller than this record day value. This may be accounted for by the fact that only one flow is taken for each year. Many years of the record will have flows, not the maximum for the year, which are much larger than the annual flood in some other years, and these secondary floods do not appear in the annual flood tabulation.

The 100 year annual flood is the annual flood expected on the average, once in 100 years, and is the ordinate read at one per cent on the time scale.

The 50 year annual flood is the annual flood expected on the average, once in 50 years, and is the ordinate read at two per cent on the time scale.

Similarly, the 10 and 5 year annual floods are read at ten per cent and twenty per cent on the time scale.

8. <u>The R. D. Goodrich Method of Straight Line Plotting of Skew Frequency Data.</u>[5] In his paper presented to the American Society of Civil Engineers in 1926, Mr. Goodrich proposed skew frequency diagrams, prepared for straight line plotting in the integral or duration curves by placing the basic equations in the logarithmic form. The equation used is:

$$t = n - n(10)^{-h(R)c} \qquad (S)$$

where t = serial number of records when arranged in order of magnitude, or the percentage of time;

n = number of records in the series, or 100 per cent;

R = value of any record in the series;

c = exponent of $f(R)$, values which are found from curve;

h = coefficient of $f(R)$, values of which are found from curve.

Considering equation (S), by transposing to the left-hand side of the equation the terms containing n and dividing both sides by -n, it becomes -

$$1 - \frac{t}{n} = (10)^{-hRc}$$

This can be transformed into the logarithmic form:

$$\log_{10}(1 - \frac{t}{n}) = -hR^c \text{ or } \operatorname{colog}_{10}(1 - \frac{t}{n}) = hR^c$$

To make a skew frequency paper on which corresponding values of the percentage of time t, and run-off R, or f(R), will plot as a linear function, it is only necessary to take the ordinary logarithmic ruling

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5. Transactions Am. Soc. C. E., Vol. 91 (Dec. 1927), p 1 et seq.

in one direction for the R or f(R) scale, and then compute a suitable series of values of log colog $(1 - \frac{t}{n})$ to give the required spacing for the t- scale.

The origin for the spacing of the t-scale is the 90 per cent line. This becomes evident since $(1 - \frac{90}{100}) = 0.1$. The colog of 0.1 is unity and the log of unity is zero. Hence, for percentages greater than 90, the ordinates laid off to the right as the log colog will be positive, while for percentages less than 90, the values will be negative and the ordinates must be laid off to the left of the line. Table 2, page 13, Transactions of the American Society of Civil Engineers, 1927, contains values for laying out the skew frequency paper, which were used for laying out this type of paper used in this study.[6]

When the first trial plotting is made, the points will usually define a curve other than straight. Then, it is necessary to determine graphically, by a few trials, the value of the constant, a, which must be added or subtracted, as the case may be, from all values of R in the record. If the first plotting of the data is concave upward, the required function for linear plotting is (R-a); if the first plotting is concave downward, the required function is (R + a).

After a is evaluated, these points are plotted, and a straight line drawn and extended graphically.

The 100 year probable annual flood is the corrected value of R corresponding to 99 per cent on the t-scale. Similarly, the 50, 10, and 5 year probable annual floods are read at 98 per cent, 90 per cent, and 80 per cent on the t-scale, respectively.

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6. See Appendix II, page 51 for reproduction of this table.

9. <u>The Monthly Flood Method</u>. The maximum daily flow in each month of the record is found. These flows are arranged in descending order of magnitude, and plotted as a cumulative frequency curve. Per cent for plotting is

$$p = \frac{100(m - 0.5g)}{n}$$

where $n =$ 12 times the number of years in the record.

If the above procedure is followed, the coefficient of variation and coefficient of skew may be found, and a skew curve of the Hazen or Foster type computed, which will fit the points. Practically, however, only the upper fraction of such a curve is of interest in a flood study, and the procedure involves such a number of terms as to be laborious; therefore, in usual practice, and in this paper, only the maximum daily flows in each month, over a stated magnitude, are used, and thus the number of points to be handled is considerably reduced. When this is done, a skew curve cannot be computed, as the series is not complete, the procedure of drawing a smooth curve to fit the points being graphical.

The 10 year, 100 year, etc., monthly flood is that record day average rate of flow expected in a long period of years to fulfill two conditions: (1) it will be a maximum for a calendar month, and (2) it will be equaled or exceeded once in 10, 100, etc., years respectively. The 10 or 100 year monthly flood is not the record day flow that is likely to be exceeded once in 10 or 100 years; the results of this study show it to be slightly smaller than the probable record day flood, but it is considerably larger than the annual flood of the same expectancy.

The 100 year monthly flood is found at $\frac{100}{12 \times 100}$ = .0833% time.

The 50 year monthly flood is found at $\frac{100}{12 \times 50}$ = .1667% time.

The 10 year monthly flood is found at $\frac{100}{12 \times 10}$ = .8333% time.

The 5 year monthly flood is found at $\frac{100}{12 \times 5}$ = 1.6667% time.

The 1 year monthly flood is found at $\frac{100}{12 \times 1}$ = 8.3333% time.

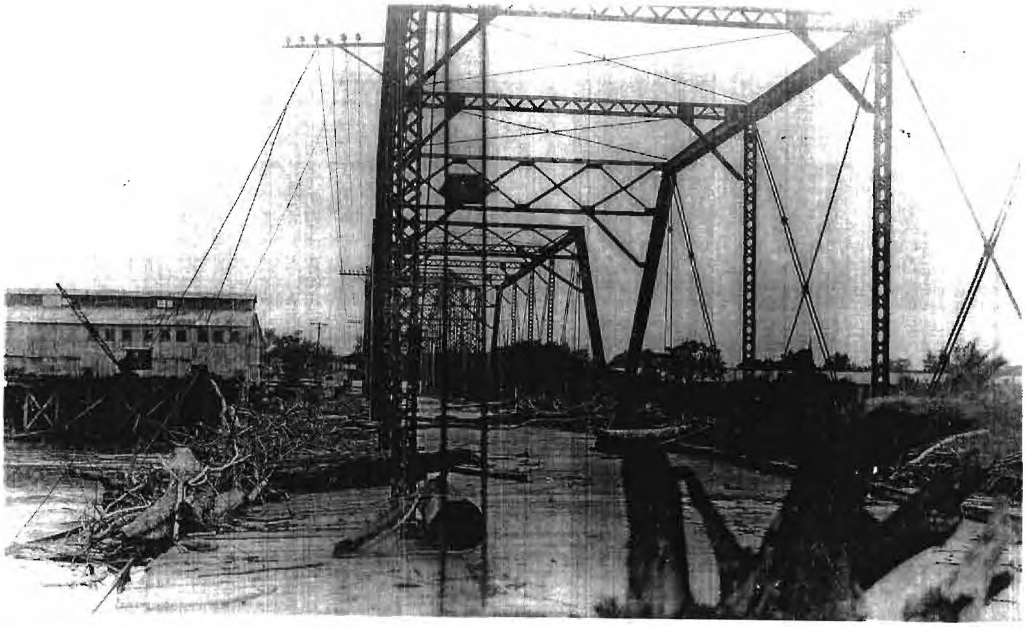
10. The Daily Flow Duration Method. This data might be worked up as a complete time series, the coefficient of variation and of skew computed, and a computed frequency curve passed through the points, but the labor involved would be very great. Instead, the usual practice is to exclude the low flows of the record. All of the daily flows above some basic stage are arranged in order of magnitude and plotted as a cumulative frequency curve. Per cent for plotting is given by the formula

$$p = \frac{100(m - 0.5g)}{n}$$

where $n = 365$ times the number of years in the record.

For the study of floods, only about two or three per cent of the time is of interest. For convenience, the basic stage (above which all daily flows are recorded, and below which all are excluded) is taken so as to give from 100 to 200 points for records of moderate length, for example, 30 years.

The duration curve may be plotted on any of the kinds of paper used in this thesis, but the more convenient is the Extreme Probability Paper, suited for a series of several thousand points, with one end of the abscissa scale extending to very small percentages of time, which are necessary to this method. The curve and its extension is drawn by estimating by eye. The ordinates of the curve so drawn show the size of



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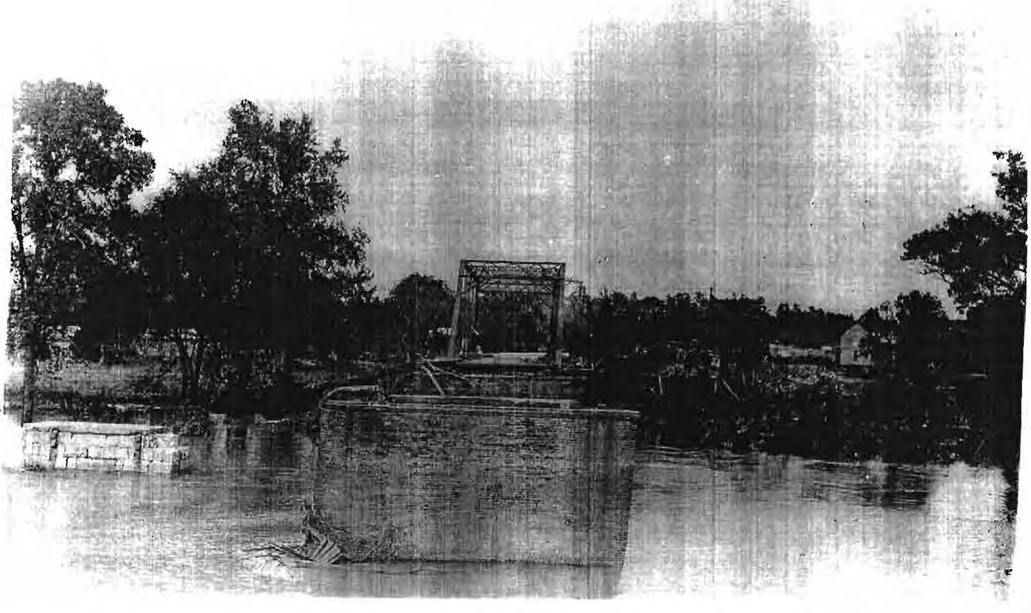
Looking toward Georgia shore; note deposit of drift on remaining spans.



U. S. Engineer Dept.

Looking toward South Carolina Shore.

BRIDGE OVER SAVANNAH RIVER AT FIFTH STREET, AUGUSTA, GA., AFTER FLOOD OF SEPTEMBER-OCTOBER 1929. (Probable frequency once in 100 years.)

the record day flood which is expected to be equaled or exceeded in the number of days represented by the corresponding abscissa.

The 100 year daily flow is that record day flow which, over a long period of time will be equaled or exceeded once in 100 years. The percentage on the time scale is that corresponding to the reciprocal of the number of days in one hundred years, namely, at 0.00274% on the probability paper. Similarly,

The 50 year daily flood is found at 0.00548% time,

The 10 year daily flood is found at 0.0274 % time,

The 5 year daily flood is found at 0.0548 % time,

The 1 year daily flood is found at 0.274 % time.

The probable daily flow for a given time interval will be larger than the probable annual, monthly, or flood peak flow for the same interval. This is because the daily flow method includes <u>all</u> flows above the basic stage, while the other methods exclude a number of secondary flows, which are larger than the primary flows in other portions of the record. By the inclusion of these secondary flows in the Daily Duration Method, they have a decided tendency to "boost" this curve as compared to the other methods.

11. <u>The Flood Event Method</u>. The maximum daily flows occurring in each flood event of the record above some designated basic stage are arranged in order of magnitude. This basic stage is usually taken as a value somewhat greater than the smallest annual flood of the record. This basic stage may be varied over a moderate range without affecting the results. Per cent for plotting is

$$p = \frac{100(m - 0.5g)}{n}$$

where n = number of flood events in the record.

Thus, this percentage for plotting is of flood peaks, not of time. This series is not a time series, and no skew curve of the Hazen or Foster type can be drawn to represent the points. The drawing in of the curve is purely graphical.

A point in this curve so drawn, represents the magnitude of the flood peak which will probably be equaled or exceeded, over a long period of years, in the per cent of flood peaks corresponding on the abscissa. That is, the magnitude corresponding to 10 per cent on the abscissa scale is the magnitude that will probably be equaled or exceeded once out of 10 flood events or peaks.

Any desired time interval can be computed and plotted on the abscissa scale by the following formula:

$$p = \frac{100y}{nI}$$

where y = number of years in the record,

n = number of flood events in the record,

I = any given time interval in years.

12. Average Number of Events per Century. The data of the Flood Event method may be converted into a time series by this method. In a given record of y years, there are n flood peaks, or an average of $\frac{n}{y}$ peaks per year, or $100\frac{n}{y}$ peaks per century. If this value, $100\frac{n}{y}$ is multiplied by the percentage of flood peaks found in the Flood Event method described above, the result will be the average number of flood peaks per century equal to or exceeding the given size.

This data cannot be plotted on probability paper, and use of logarithmic scales in both directions is usually the most suitable method of plotting. The flood value on the curve corresponding to 1 flood per century is the flood peak which will probably be equaled or exceeded once in one hundred years. Similarly, the

50 year peak is found at 2 floods per century,

10 year peak is found at 10 floods per century,

5 year peak is found at 20 floods per century,

1 year peak is found at 100 floods per century.

The data presented is essentially the same as that of the Flood Event method; but it has the advantage that magnitudes for any time interval may be read directly without the necessity of computing abscissa values for the desired intervals.

13. The Fuller Formula. The large number of factors which combine in producing floods may be divided into two broad groups, viz., (1) those depending on the physiography of the basin, and (2) those depending on the weather. Any rational flood formula must take both of these classes of factors into account, and therefore must be made up of two parts. One of these parts should represent the physical characteristics of the stream; this would be a constant for a given point but would vary for different points on the same stream, and still more for different streams. The second part would represent a probability law which would be practically the same for a large area, but not necessarily the same for all watersheds.

The Fuller Formula[7] contains these two factors. It is -

$$Q = CA^{0.8}(1 + 0.8 \log T)$$

where Q = the largest 24 hour average rate of flow to be expected in a period of T years;

T = the number of years in the period considered (i.e., any time interval for which probable flood is desired);

C = A coefficient which is constant for the river at the point of observation;

A = The drainage area in square miles.

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7. Transactions AM. Soc. C. E. Vol. 77, (1914) p. 567.

14. <u>The Pettis Width Formula.</u>[8] The Pettis Width Formula fulfills the requirements for a rational flood formula, as stated in paragraph 13 above. Colonel Pettis is of the opinion, substantiated by his extensive studies, that within certain limits of size, the shape of the drainage basin, rather than its slope and ruggedness, is a controlling factor in the flood flows which obtain. He has found that the index of this is the average width of the basin, and that the flood discharges vary, not with the first power of the average width, but as the 5/4 power of this width. The average width is obtained by dividing the drainage area in square miles at the station by the length of the river and its longest tributary in miles; this length is measured from a map (of scale, e.g., 1:500,000), ignoring all minor sinuosities, and following the tributary which will give the longest length to its headwaters.

The second, or weather factor, in this formula is the probable rainfall. Colonel Pettis makes use of an isohyetal map of probable 6-day rainfall to determine the value of the second factor. This isohyetal map (see Plate 6, following page 51) was prepared by the Miami Conservancy District engineering staff and published in its technical reports.

The Pettis Formula is:

$$Q = CPW^{5/4}$$

where Q = probable 100 year maximum discharge;

C = a constant; the value 328 is used for all rivers east of the Mississippi;

W = average width of drainage area in miles;

P = probable 100 year maximum 6-day rainfall in inches.

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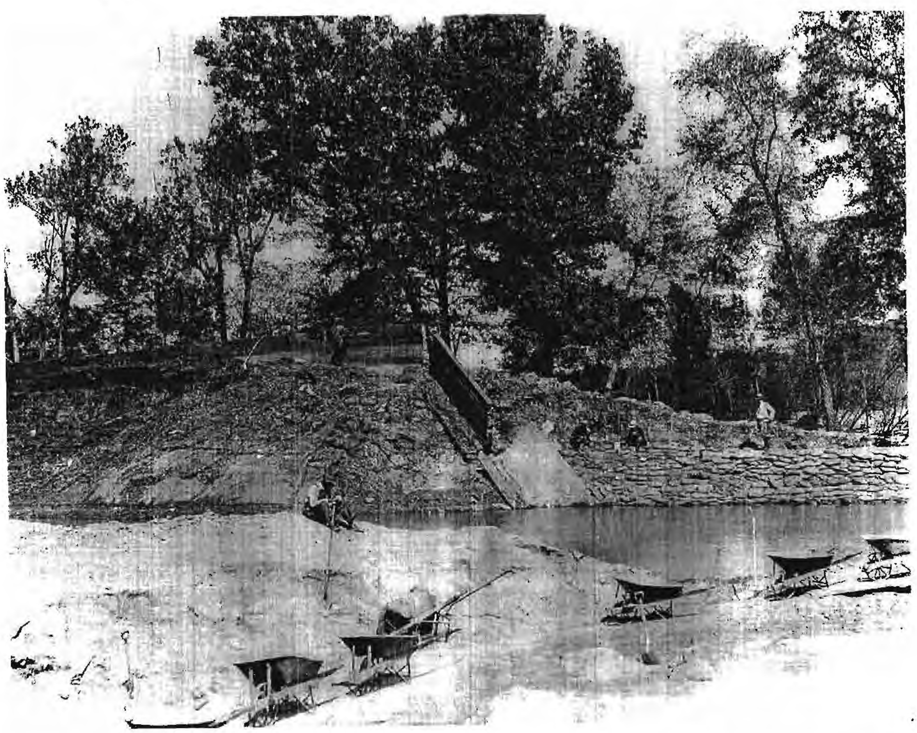
8. A New Theory of River Flood Flow, by Lt. Col. (then Major) C. R. Pettis, Corps of Engineers, U. S. Army, 1927.

The application of the formula is limited to areas between 1000 and 10,000 square miles in size. There is a further limitation and a very important one, that the tributary area must not contain an extensive amount of storage, either natural storage, such as lakes or extremely large swamps, or artificial, as large storage reservoirs. The 6-day rainfall period is taken, because for the eastern United States, this period takes in practically all the rainfall that pertains to a particular storm, and excludes rains that more properly belong to some other different storm. Furthermore, for drainage areas within the size range given, practically all the rain that falls within six days will have some effect on the discharge.

U. S. Engineer Dept.

Southern Railway Bridge; note missing spans in background, and accumulation of drift.



U. S. Engineer Dept.

Break in bank of Augusta Power Canal.

EFFECTS OF SEPTEMBER-OCTOBER 1929 FLOOD AT AUGUSTA, GA.

APPLICATION OF METHODS

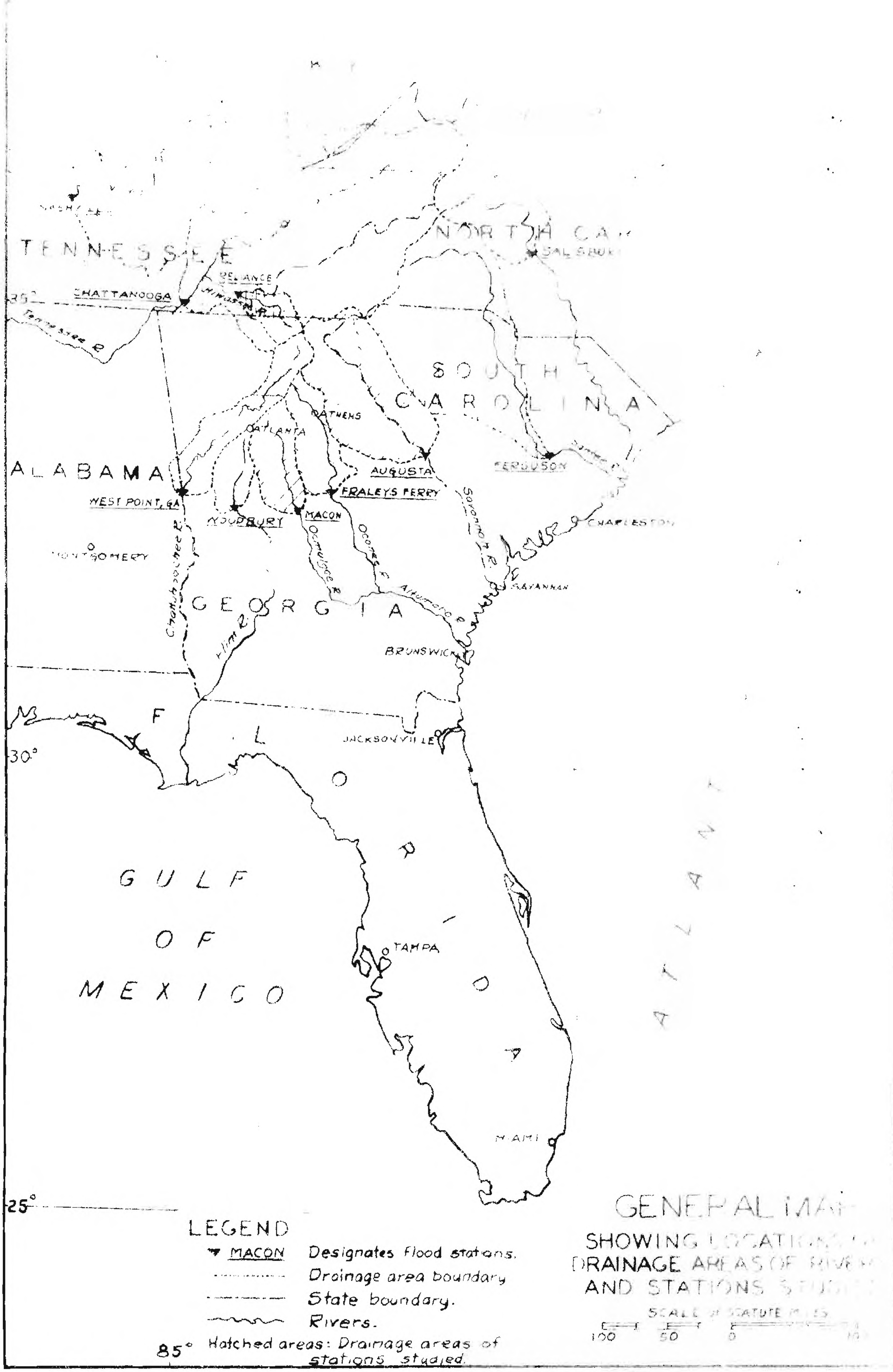
15. General. For this study, which is limited to streams in the southeastern United States, a group of ten stations on as many rivers have been selected, representing a wide variety of topographic and hydrological conditions, and in size of drainage area. The stations selected were those having the longest and most accurate records of flow for which data were available. Those stations and streams considered are given in Table I, Plate 1, following this page, shows on a general map those stations studied.

TABLE I

River	Station	Drainage Area Sq. Mi.	Record	
			Dates	Length in Years
Chattahoochee	West Point, Ga.*	3,550	1896-1932	35
Cumberland	Nashville, Tenn.	12,860	1887-1931	44
Flint	Woodbury, Ga.	1,090	1900-1922	22
Hiwassee	Reliance, Tenn.	1,180	1900-1932	32
Ocmulgee	Macon, Ga.	2,283	1895-1931	37
Oconee	Fraleys Ferry, Ga.*	2,815	1904-1931	28
Santee	Ferguson, S. C.	14,800	1908-1929	22
Savannah	Augusta, Ga.	7,245	1876-1932	57
Tennessee	Chattanooga, Tenn.	21,400	1874-1932	58
Yadkin	Salisbury, N. C.*	3,400	1907-1927	19

*One or more years missing.

By far the most comprehensive records of flow of streams in this country are those compiled and published by the United States Geological Survey, in their yearly series of Water Supply Papers. These records have furnished the bulk of the data used in this paper. However, supplementary record data was obtained from the files of the United States Engineer Office, Savannah, Georgia, and from records of Daily River Stages, published by the United States Weather Bureau, and from flow records of private power companies interested in different streams. A statement



TENNESSEE
NORTH CA
SOUTH CAROLINA
ALABAMA
GEORGIA
FLORIDA
GULF OF MEXICO
CHATTANOOGA
RELIANCE
Hiwassee R.
Tennessee R.
ATHENS
ATLANTA
AUGUSTA
FRALEYS FERRY
WEST POINT, GA
WOODBURY
MACON
FERGUSON
CHARLESTON
SAVANNAH
BRUNSWICK
JACKSONVILLE
TAMPA
MIAMI
MONTGOMERY
Chattahoochee R.
Flint R.
Ocmulgee R.
Oconee R.
Altamaha R.
Savannah R.
35°
30°
25°
85°
LEGEND
MACON Designates flood stations.
Drainage area boundary
State boundary.
Rivers.
Hatched areas: Drainage areas of stations studied.
GENERAL MA
SHOWING
DRAINAGE AREAS OF
AND STATIONS
100 50 0

as to the source of the record of each station studied in this paper is given in Appendix IV.

Each station is studied, in the order listed in Table I, applying every method applicable at each location. The results, in terms of flood magnitudes for various intervals of time, for all stations and for all methods considered, are assembled in tabulated form, and conclusions will be drawn therefrom as to the significance and value of the different methods of analysis. All computations necessary for applying every method to one station are given. For the remaining stations, brief tabulated computations are given in Appendix III.

As an example of the detailed computations required, the record of the Chattahoochee River at West Point, Georgia, is selected, analysis of which follows.

16. Chattahoochee River at West Point -- Analysis by Annual Flood Method. Table II below gives the tabulated computations necessary to determine the coefficient of variation and coefficient of skew which define the skew curve which will best represent the points of the series. Columns 4 and 5 give the values for plotting the individual points of the series. Since in this method, flows of identical magnitude are not grouped, the formula for per cent for plotting is $p = \frac{100(m - 0.5)}{n}$.

TABLE II

Chattahoochee River at West Point, Georgia. Annual Flood Computations.
35 year record, October, 1896 - September, 1932.

Year	Maximum Daily Disch. c.f.s.	Disch. in Order of Size	Plotting Position	In Terms of Mean	Difference from 1	Difference Squared	Cube of Difference +	-
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1896-97	38,500	134,000	1.43	2.90	+ 1.90	3.600	6.860	
1897-98	57,350	88,630	4.29	1.916	0.916	0.839	0.770	
1898-99	43,550	85,000	7.15	1.838	.838	.700	.585	
1899-00	63,330	75,500	10.00	1.632	.632	.399	.252	
1900-01	52,750	66,090	12.85	1.430	.430	.185	.080	
1901-02	88,630	63,700	15.71	1.375	.375	.141	.053	
1902-03	66,090	63,330	18.58	1.365	.365	.134	.049	
1903-04	29,340	61,600	21.42	1.340	.340	.116	.039	
1904-05	29,340	57,350	24.30	1.238	.238	.057	.013	
1905-06	50,800	54,200	27.15	1.170	.170	.029	.005	
1906-07	28,800	52,750	30.00	1.140	.140	.020	.003	
1907-08	40,500	51,200	32.90	1.110	.110	.012	.001	
1908-09	51,200	50,800	35.71	1.095	.095	.009	.001	
1909-10	22,800	50,600	38.57	1.093	.093	.009	.001	
1911-12	61,600	48,800	41.43	1.055	.055	.003	.000	
1912-13	45,000	45,000	44.29	0.973	-.027	.001		.000
1913-14	16,800	43,350	47.14	.936	.064	.004		.000
1914-15	23,500	42,800	50.00	.926	.074	.005		.000
1915-16	48,800	40,500	52.86	.875	.125	.016		.002
1916-17	42,800	38,500	55.71	.832	.168	.028		.005
1917-18	34,800	37,100	58.57	.801	.199	.040		.008
1918-19	63,700	34,800	61.43	.752	.248	.062		.015
1919-20	134,000	29,500	64.29	.638	.362	.131		.048
1920-21	50,600	29,340	67.14	.634	.366	.134		.049
1921-22	54,200	29,340	70.00	.634	.366	.134		.049
1922-23	37,100	28,800	72.86	.622	.378	.143		.054
1923-24	25,400	27,000	75.71	.584	.416	.174		.072
1924-25	85,000	26,400	78.57	.570	.430	.185		.080
1925-26	26,400	26,400	81.43	.570	.430	.185		.080
1926-27	22,100	25,800	84.29	.558	.442	.196		.086
1927-28	27,000	25,400	87.14	.549	.451	.204		.093
1928-29	75,500	23,500	90.00	.509	.491	.241		.119
1929-30	25,800	22,800	92.86	.493	.507	.258		.130
1930-31	29,500	22,100	95.71	.477	.523	.274		.143
1931-32	26,400	16,800	98.57	.363	.637	.407		.260
Total		1,618,780		34.993		9.075	8.712	1.293
Mean Flood		46,251						

$$\text{Coefficient of Variation} = \sqrt{\frac{9.075}{35 - 1}} = 0.516$$

$$\text{Coefficient of Skew} = \frac{8.712 - 1.293}{(35 - 1)(0.516)^3} = 1.580$$

Since the coefficient of skew is affected by the number of terms in the record, the Hazen and Foster skew curve factors were computed for a long term series. Inasmuch as all flow records are relatively short, the coefficient of skew must be corrected by the formula:

$$\text{Coefficient of Skew (adjusted)} = \text{Coefficient of Skew (computed)} \left(1 + \frac{8.5}{n}\right).$$

Thus the coefficient of Skew (adjusted) $= 1.580\left(1 + \frac{8.5}{35}\right)$

$$= 1.965.$$

Then by referring to the tables of skew curve factors (see pages 49-50, Appendix II), the following tabulated computations are made, giving co-ordinates of skew curves to fit the West Point record, for both the Hazen Logarithmic Probability Curve and the Foster Type III curve.

CALCULATION OF PLOTTING POINTS TO DRAW A SMOOTH LINE
Coefficient of Variation = 0.516. Coefficient of Skew = 1.965.

Plotting Point, per cent	Factor from Probability Table, Corresponding to C.S., to be multiplied by C. V.	Product of Factor and C. V.	One plus product being plotting position in terms of mean flood.
	Hazen Logarithmic Probability Curve		
99	1.21	-0.625	0.375
95	1.06	.547	.450
80	0.77	.398	.600
50	.27	.140	.860
20	.61	+ .315	1.315
5	2.05	1.070	2.070
1	4.03	2.080	3.080
0.1	7.60	3.930	4.930
	Foster's Type III Curve		
99	0.99	-0.511	0.49
95	.95	.490	.51
80	.78	.402	.60
50	.31	.160	.84
20	.61	+ .315	1.315
5	2.00	1.032	2.030
1	3.60	1.860	2.860
0.1	5.91	3.05	4.05

These curves, and the record points are plotted on Plate 2, Figure 1, following this page.

PLATE 2

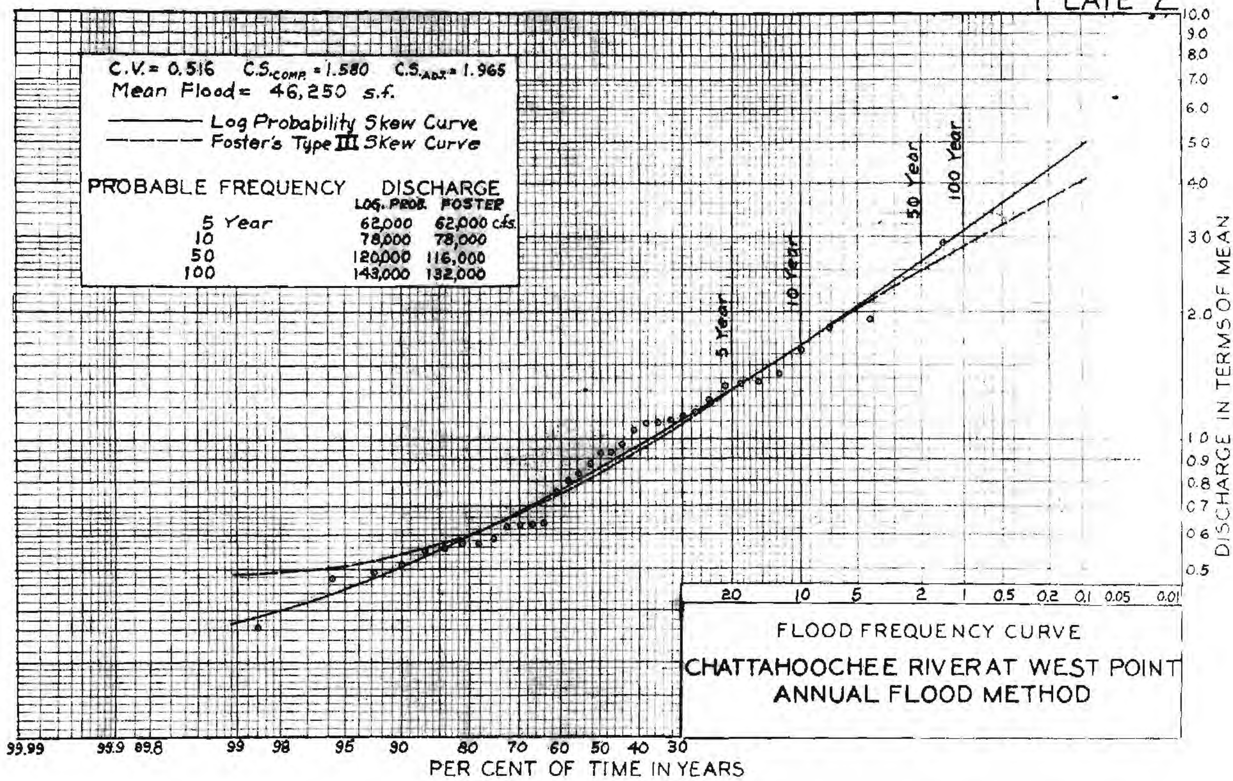


FIGURE 1

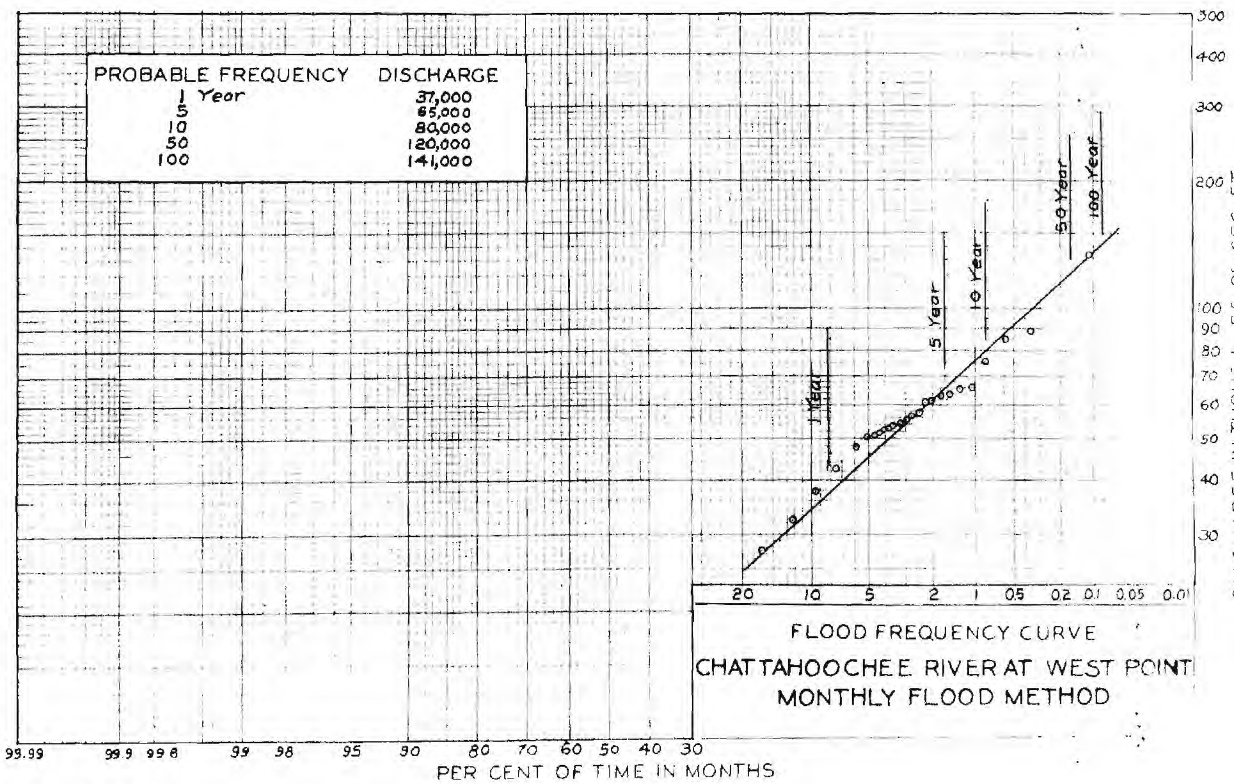


FIGURE 2

17. Chattahoochee River at West Point -- Goodrich Straight Line Plotting Method. Table III below gives the tabulated computations for plotting by this method. Columns one and two contain the same data as the Annual Flood Method; except that the values of discharge (R) are in ascending order of magnitude. The values of columns 1 and 2 are plotted on skew frequency paper (see Plate 3 following page 30). This plotting is concave upward. Therefore, the function of discharge necessary to give a straight line is (R - a). After a few trials, it is found that with a value of "a" = 0.35 (in terms of mean discharge) the points will arrange themselves in approximately a straight line; i.e., a straight line will represent these points better than any cuver. For probable floods, values of R - 0.35 are read from the curve at the proper percentages. These values plus 0.35 give the probable flood value in terms of the mean.

TABLE III

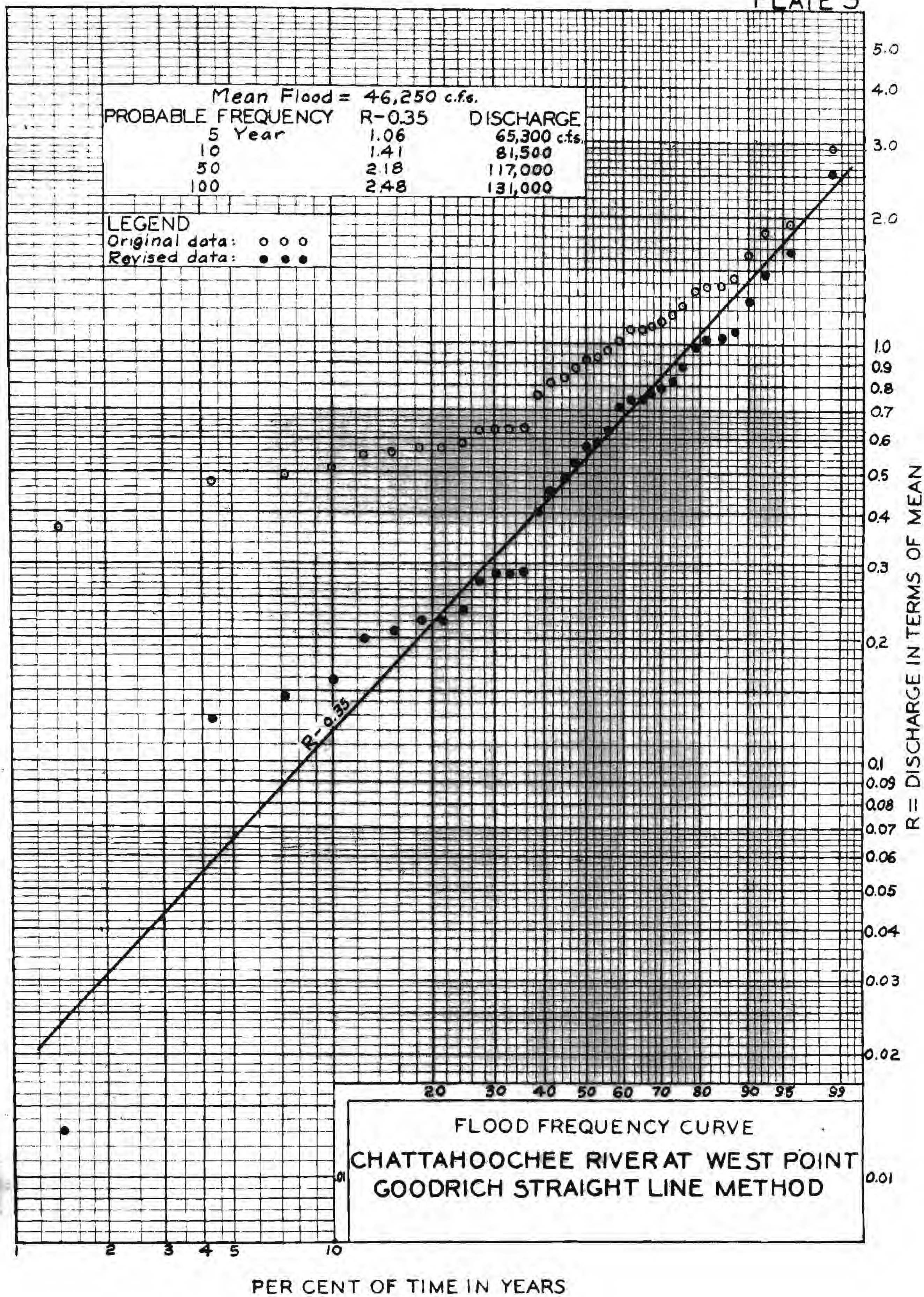
Chattahoochee River at West Point, Georgia. Goodrich Straight Line Method. Tabulated data. 35 year record, Oct. 1896 - Sept. 1932.

R = Discharge Arranged in Order of Magnitude c.f.s.	Per cent time for plotting.	R in terms of mean.	R - 0.35
16,800	1.43	0.363	0.013
22,100	4.29	.477	.127
22,800	7.14	.493	.143
23,500	10.00	.509	.159
25,400	12.86	.549	.199
25,800	15.71	.558	.208
26,400	18.57	.570	.220
26,400	21.43	.570	.220
27,000	24.29	.584	.234
28,800	27.14	.622	.272
29,340	30.00	.634	.284
29,340	32.86	.634	.284
29,500	35.71	.638	.288
34,800	38.57	.752	.402
37,100	41.43	.801	.451
38,500	44.29	.832	.482
40,500	47.14	.875	.525
42,800	50.00	.926	.576
43,350	52.86	.936	.586
45,000	55.71	.973	.623
48,800	58.57	1.055	.705
50,600	61.43	1.093	.743
50,800	64.29	1.095	.745
51,200	67.14	1.110	.760
52,750	70.00	1.140	.790
54,200	72.86	1.170	.820
57,350	75.71	1.238	.888
61,600	78.57	1.340	.990
63,330	81.43	1.365	1.015
63,700	84.29	1.375	1.025
66,090	87.14	1.430	1.080
75,500	90.00	1.632	1.282
85,000	92.86	1.838	1.488
88,630	95.71	1.916	1.666
134,000	98.57	2.900	2.550

Mean
Flood = 46,251

This data is plotted on Plate 3, following this page.

PLATE 3



FLOOD FREQUENCY CURVE
CHATTAHOOCHEE RIVER AT WEST POINT
GOODRICH STRAIGHT LINE METHOD

18. Chattahoochee River at West Point -- Monthly Flood Method.

Table IV gives the tabulated computations for analysis by this method. In this tabulation when more than one flood of the same magnitude occurs, they are grouped, the point representing the group being plotted at the middle of the group on the time scale. Also, in the lower part of the curve, to avoid a large number of points very close together, flows are grouped between limited ranges; e.g., the six flows between 50,000 and 45,000 second feet are plotted at 47,500 second feet and represented by one point.

TABLE IV

Chattahoochee River at West Point, Georgia, Monthly Flood computations.
35 year record, October 1896 - September 1932.
(Flows above 25,000 c.f.s.)

Flood Limits	g	M	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
134,000		1	0.119
88,630		2	.357
85,000		3	.595
75,500		4	.834
66,090		5	1.071
65,630		6	1.310
63,700		7	1.550
63,330		8	1.785
61,600		9	2.025
61,030		10	2.260
57,350		11	2.50
56,430		12	2.74
55,510		13	2.98
54,200	2	15	3.33
53,600		16	3.69
52,750		17	3.93
52,290		18	4.16
51,200		19	4.40
50,800		20	4.64
50,600		21	4.87
50,500		22	5.13
50,000-45,000	6	28	5.95
45,000-40,000	7	35	7.50
40,000-35,000	10	45	9.53
35,000-30,000	13	58	12.27
30,000-25,000	25	83	16.80

$n = 35 \times 12 = 420$

Plate 2, figure 2, following page 28, shows the plotted curve and magnitudes for different time intervals.

19. Chattahoochee River at West Point, Georgia -- Daily Flow Duration Method. Table V shows the tabulated computations for this method.

TABLE V

Chattahoochee River at West Point, Georgia. Daily Flow Duration computations. 35 year record, October 1896 - September 1932. (Flows above 30,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting $= \frac{100(m - 0.5g)}{n}$
134,000		1	0.00392
88,600		2	.0118
85,000		3	.0196
80,400		4	.0274
75,500	2	6	.0392
71,400		7	.0510
66,100		8	.0588
65,600	2	10	.0705
64,400		11	.0823
63,900		12	.0901
63,700		13	.0980
63,300		14	.1059
62,000-60,000	4	18	.1250
60,000-58,000	4	22	.1560
58,000-56,000	3	25	.1832
56,000-54,000	7	32	.2220
54,000-52,000	7	39	.2785
52,000-50,000	6	45	.3280
50,000-45,000	18	63	.424
45,000-40,000	40	103	.650
40,000-35,000	42	145	.972
35,000-30,000	50	195	1.330

$n = 35 \times 365 = 12,775$

Plate 4, figure 1, following this page shows the plotted curve, and magnitudes for various time intervals.

20. Chattahoochee River at West Point -- Flood Event Method. Table VI shows the computations for this method. As stated before, the percentages are in terms of flood peaks and not in terms of time. To get the interval for any flood magnitude,

$$\text{Percentage of time} = \frac{100 \times \text{number of years of record}}{\text{number of flood peaks} \times \text{interval in years.}}$$

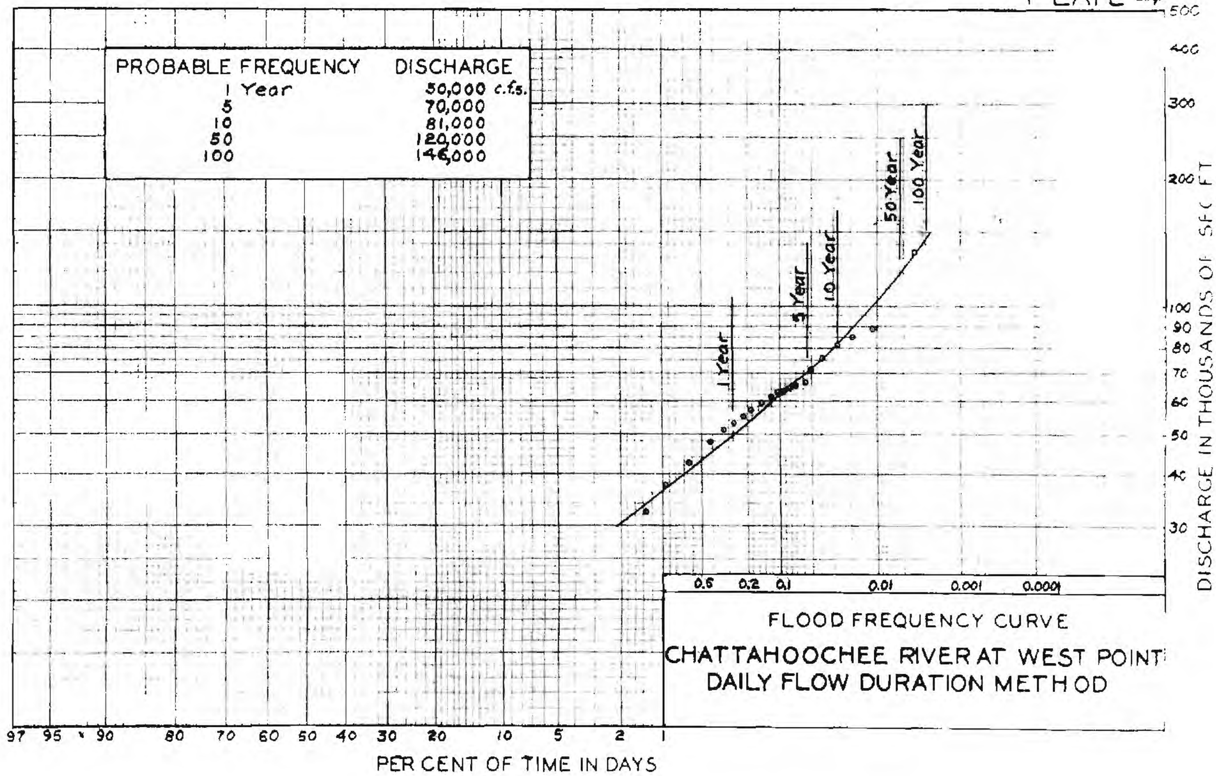


FIGURE 1

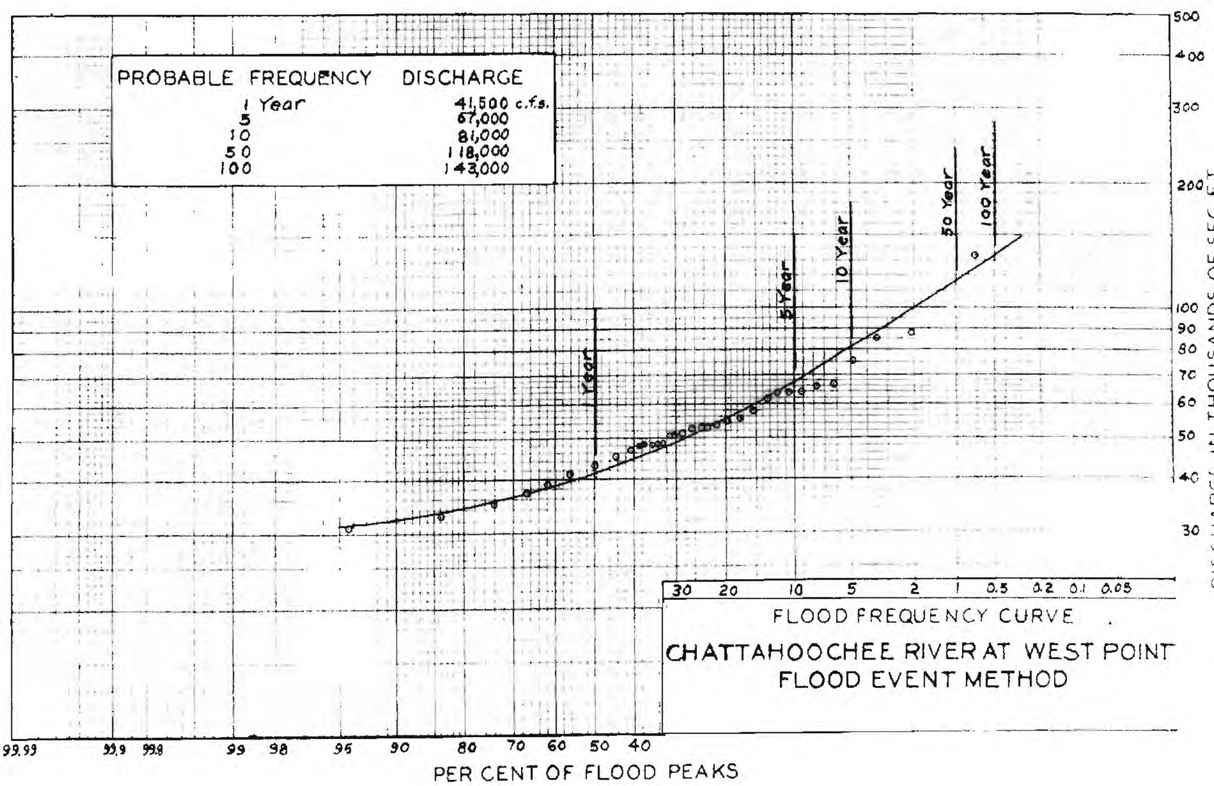


FIGURE 2

For 100 year interval this $= \frac{100 \times 35}{71 \times 100} =$ 0.493 per cent,

similarly, the 50 year interval = 0.986 per cent,

the 10 year interval = 4.93 per cent,

the 5 year interval = 9.86 per cent,

the 1 year interval = 49.30 per cent.

TABLE VI

Chattahoochee River at West Point, Georgia. Flood Event Method computations. 35 year record. October 1896 - September, 1932.
(Peak of each freshet above 30,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting $= \frac{100(m - 0.5g)}{n}$
134,000		1	0.705
88,600		2	2.12
85,000		3	3.52
75,500		4	4.93
66,100		5	6.35
65,600		6	7.75
63,900		7	9.16
63,700		8	10.57
63,300		9	12.00
61,600		10	13.40
57,400	2	12	15.50
55,500		13	17.60
54,200	2	15	19.75
53,600		16	21.80
52,800		17	23.25
52,400		18	24.65
52,300	2	20	26.80
51,200		21	28.85
50,800		22	30.3
50,500		23	31.7
48,800		24	38.1
48,600		25	34.5
48,500		26	35.9
48,200		27	37.4
47,900		28	38.7
46,800	2	30	40.9
46,000-44,000	3	33	44.4
44,000-42,000	5	38	50.0
42,000-40,000	4	42	56.4
40,000-38,000	4	46	62.0
38,000-36,000	3	49	67.0
36,000-34,000	7	56	74.0
34,000-32,000	7	63	83.9
32,000-30,000	8	71	94.4

$n = 71$

Plate 4, figure 2, following page 32 shows the plotted curve and results for different time intervals.

21. <u>Chattahoochee River at West Point -- Average Number of Events per century or Modified California Method</u>. In this method, essentially, columns 1 and 4 of the Flood Event Method (Table VI) are taken as a starting point, and converted into a time series. The average number of events per century is given by the formula

$$\text{Number of Events/Century} = \frac{\text{number of events in record x 100}}{\text{number of years in record}}$$

$$= \frac{71}{35} \times 100 = 202.5.$$

If this is multiplied by the percentages of flood peaks for any magnitude, the result will be the average number of events per century of that magnitude.

Table VII gives these computations. The first four columns are taken directly from Table VI, being repeated to avoid necessity for references to another page.

TABLE VII

Chattahoochee River at West Point, Georgia. Computations for Average Number of Events per Century Method. 35 year record, Oct. 1896-Sept. 1932.

(Peak of each freshet above 30,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - .5g)}{n}$	Average number of events per century = 202.5 x per cent of flood peaks.
134,000		1	0.705	1.43
88,600		2	2.12	4.30
85,000		3	3.52	7.15
75,500		4	4.93	10.0
66,100		5	6.35	12.9
65,600		6	7.75	15.7
63,900		7	9.16	18.6
63,700		8	10.57	21.4
63,300		9	12.00	24.3
61,600		10	13.40	27.2
57,400	2	12	15.50	31.4
55,500		13	17.60	35.7
54,200	2	15	19.75	40.0
53,600		16	21.80	44.2
52,800		17	23.25	47.1
52,400		18	24.65	50.0
52,300	2	20	26.80	54.4
51,200		21	28.85	58.5
50,800		22	33.00	61.5
50,500		23	31.70	64.4
48,800		24	38.1	67.1
48,600		25	34.5	70.0
48,500		26	35.9	73.0
48,200		27	37.4	76.0
47,900		28	38.7	78.5
46,800	2	30	40.9	83.0
46,000-44,000	3	33	44.4	90.0
44,000-42,000	5	38	50.0	101.5
42,000-40,000	4	42	56.4	114.3
40,000-38,000	4	46	62.0	125.8
38,000-36,000	3	49	67.0	136.0
36,000-34,000	7	56	74.0	150.2
34,000-32,000	7	63	83.9	170.0
32,000-30,000	8	71	94.4	191.2

The curve is plotted and results given on Plate 5, following this page.

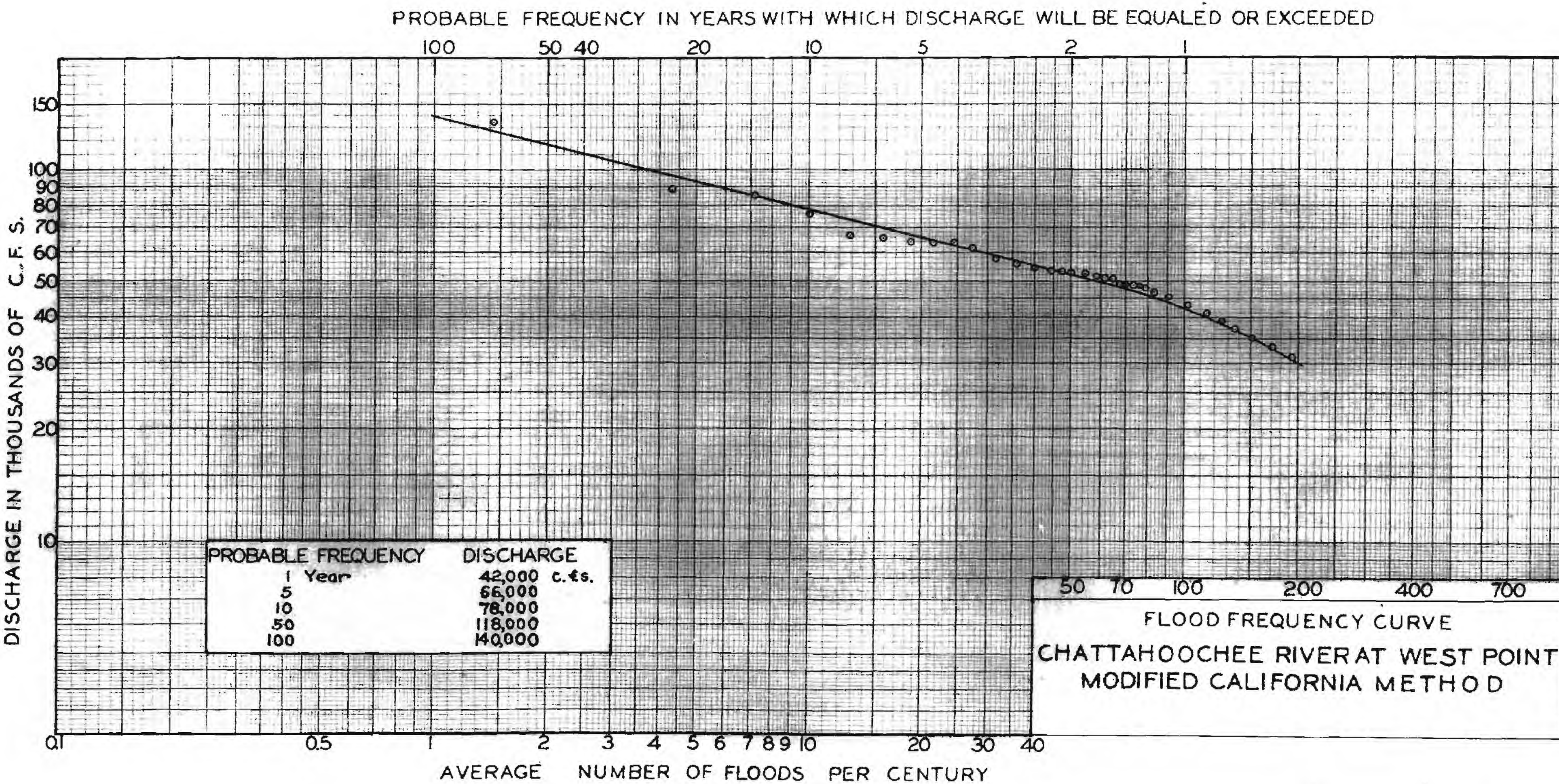

PROBABLE FREQUENCY IN YEARS WITH WHICH DISCHARGE WILL BE EQUALED OR EXCEEDED
100
50 40
20
10
5
2
1
DISCHARGE IN THOUSANDS OF C. F. S.
150
100
90
80
70
60
50
40
30
20
10
PROBABLE FREQUENCY DISCHARGE
1 Year 42,000 c.f.s.
5 66,000
10 78,000
50 118,000
100 140,000
50 70 100 200 400 700
FLOOD FREQUENCY CURVE
CHATTAHOOCHEE RIVER AT WEST POINT
MODIFIED CALIFORNIA METHOD
0.1
0.5
1
2
3
4
5 6 7 8 9 10
20
30
40
AVERAGE NUMBER OF FLOODS PER CENTURY

PLATE 5

22. Chattahoochee River at West Point -- The Fuller Formula.

The fuller Formula is -

$$Q = CA^{0.8}(1 + 0.8 \log T) \qquad (1)$$

where T = the number of years in the period considered (i.e., the time interval for which the probable flood is desired);

C = a constant for the river at the point of observation;

A = drainage area in square miles.

The only term which is difficult to evaluate is C. Mr. Fuller used two methods of approximating this term. Both involve an inverse solution of formula (1) above, using known values of discharge. One method used was to substitute the largest flood on record, the average of the two largest, and the average of the three largest, respectively, in the formula and determine three approximate values of C. Since the time T necessarily had to be taken as the length of the available record, these determinations of C were subject to considerable error. The second method of approximating C is based on the average flood; then $C = \frac{Q(\text{ave.})}{A^{0.8}}$. This method is more accurate where a record of fifteen years or more is available, as the average flood is usually well determined by a record of that length. The second method is used in this paper.

The drainage area of the Chattahoochee River at West Point is 3550 square miles.

$$A^{0.8} = 691$$

$$Q(\text{ave}) = 46{,}250 \text{ c.f.s.}$$

$$\text{then} \quad C = \frac{46{,}250}{691} = 66.9$$

Using these values of C and $A^{0.8}$, tabulated computations for different time intervals are given below.

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	66.9	691	1.60	2.60	120,000
50			1.36	2.36	109,000
10			0.80	1.80	83,000
5			0.56	1.56	72,000

It is apparent that in using a value of C determined from the mean flood, that the discharge for any interval of time is the mean flood multiplied by a time factor (1 + 0.8 log T).

23. Chattahoochee River at West Point -- The Pettis Width Formula.

The Pettis Width Formula is -

$$Q = 328\ PW^{5/4}$$

where Q = maximum probable 100 year discharge in c.f.s.,

P = probable 100 year six day rainfall in inches,

W = average width of drainage area in miles.

The drainage area of the Chattahoochee at West Point is 3550 square miles.

The length of the river, as measured from a map of scale 1:500,000, was found to be 211 miles.

$$\text{Then } W = \frac{3550}{211} = 16.8 \text{ miles,}$$

$$\text{and } W^{5/4} = 33.95$$

From Isopluvial chart of probable 100 year 6 day rainfall (see Plate 6, following page 51) -

$$P = 13 \text{ inches.}$$

$$\text{Then } Q = 328 \times 13 \times 33.95$$

$$= 145{,}000 \text{ c.f.s.}$$

COMPARISON OF RESULTS

24. In Table VIII, below, is presented a comparison at each station of the results for different time intervals, of flood flow analysis by the methods studied in this paper.

TABLE VIII

COMPARISON OF RESULTS BY DIFFERENT METHODS

Method of Analysis	Probable Frequency in Years					100 Year Peak Flow = 100 yr. Ave. Daily x Factor.
	1	5	10	50	100	
Chattahoochee River at West Point, Georgia						Factor = 1.17
Daily Flow	50,500	72,000	81,000	121,000	146,000	171,000
Flood Events	41,500	67,000	81,000	121,000	143,000	167,000
Events per Century	42,000	66,000	78,000	118,000	140,000	164,000
Monthly Flood	37,000	65,500	79,000	120,000	141,000	165,000
Annual Fld. (Hazen)		62,000	78,000	120,000	143,000	167,000
Annual " (Foster)		62,000	78,000	116,000	132,000	154,000
Goodrich St. Line		65,300	81,500	117,000	131,000	153,000
Fuller's Formula		72,000	83,000	109,000	120,000	140,500
Pettis' Formula						145,000
Cumberland River at Nashville, Tennessee						Factor = 1.12
Daily Flow	142,000	169,000	182,000	211,000	225,000	251,000
Flood Events	107,000	142,000	156,000	190,000	205,000	228,000
Events per Century	108,000	140,000	151,000	188,000	206,000	230,000
Monthly Flood	113,000	148,000	162,000	196,000	211,000	235,000
Annual Fld. (Hazen)		138,000	153,000	166,000	197,000	220,000
Annual " (Foster)		138,000	153,000	165,000	195,000	218,000
Goodrich St. Line		131,000	158,500	188,000	198,000	221,000
Fuller's Formula		182,000	210,000	276,000	304,000	340,000
Pettis' Formula						217,000
Flint River near Woodbury, Georgia						Factor = 1.25
Daily Flow	20,000	28,000	32,000	40,500	45,000	56,000
Flood Events	15,300	25,000	29,200	39,000	43,500	54,200
Events per Century	15,400	25,500	29,400	37,400	42,200	52,600
Monthly Flood	14,400	25,100	29,400	38,800	42,000	52,400
Annual Fld. (Hazen)		24,900	29,600	38,100	41,600	52,000
Annual " (Foster)		24,900	29,600	38,100	41,400	51,500
Goodrich St. Line		24,900	29,000	37,100	40,100	50,000
Fuller's Formula		27,500	32,000	41,500	46,000	57,400
Pettis' Formula						178,000

TABLE VIII. COMPARISON OF RESULTS BY DIFFERENT METHODS (contd.)

Method of Analysis	Probable Frequency in Years					100 Year Peak Flow = 100 yr. Ave. Daily x Factor
	1	5	10	50	100	
Hiawassee River at Reliance, Tennessee						
						Factor = 1.24
Daily Flow	24,000	37,000	43,500	60,000	68,000	84,400
Flood Events	22,000	35,500	42,000	58,500	67,000	83,100
Events per Century	22,000	36,000	42,000	59,000	67,000	83,100
Monthly Flood	21,000	35,500	42,000	59,000	66,500	82,500
Annual Fld. (Hazen)		34,800	41,900	56,200	62,300	77,300
Annual " (Foster)		34,800	41,900	55,700	61,400	76,200
Goodrich St. Line		35,000	42,000	55,700	61,400	76,200
Fuller's Formula		39,200	45,200	59,500	65,500	81,400
Pettis' Formula						109,000
Ocmulgee River at Macon, Georgia						
						Factor = 1.20
Daily Flow	31,000	46,000	52,500	71,000	80,000	98,000
Flood Events	24,000	39,000	47,000	68,000	79,000	94,500
Events per Century	24,500	41,000	48,000	64,500	72,000	86,000
Monthly Flood	22,500	40,500	48,000	62,000	69,000	82,500
Annual Fld. (Hazen)		38,400	46,400	62,000	69,400	83,000
Annual Fld. (Foster)		38,400	45,500	61,000	67,000	80,100
Goodrich St. Line		38,700	46,600	61,500	68,100	81,500
Fuller's Formula		45,200	52,200	68,500	75,500	90,500
Pettis' Formula						182,000
Oconee River at Fraley's Ferry, Georgia						
						Factor = 1.19
Daily Flow	43,000	64,000	77,000	107,000	125,000	148,000
Flood Events	29,000	57,000	71,000	106,000	124,000	147,000
Events per Century	29,000	57,000	71,000	104,000	124,000	147,000
Monthly Flood	26,000	55,000	70,000	103,000	120,000	142,500
Annual Fld. (Hazen)		49,300	62,000	92,500	106,000	125,500
Annual " (Foster)		49,300	62,000	90,500	100,000	118,500
Goodrich St. Line		50,000	61,000	83,100	92,000	109,000
Fuller's Formula		57,000	66,000	86,000	95,000	112,500
Pettis' Formula						202,000
Santee River at Ferguson, South Carolina						
						Factor = 1.11
Daily Flow	185,000	300,000	350,000	490,000	570,000	635,000
Flood Events	79,000	190,000	256,000	460,000	570,000	635,000
Events per Century	81,000	190,000	255,000	460,000	570,000	635,000
Monthly Flood	80,000	180,000	242,000	440,000	550,000	612,000
Annual Fld. (Hazen)		191,000	260,000	434,000	524,000	582,000
Annual Fld. (Foster)		191,000	258,000	407,000	477,000	532,000
Goodrich St. Line		196,000	267,000	428,000	500,000	557,000
Fuller's Formula		205,000	236,000	310,000	341,000	385,000
Pettis' Formula						548,000

TABLE VIII. COMPARISON OF RESULTS BY DIFFERENT METHODS (contd.).

Method of Analysis	Probable Frequency in Years					100 Year Peak Flow = 100 yr. Ave. Daily x Factor.
	1	5	10	50	100	
Savannah River at Augusta, Georgia[1] (All values are Peak Flows.)						
Daily Flow						
Flood Events		165,000	205,000	320,000	380,000	
Events per Century		165,000	205,000	320,000	380,000	
Monthly Flood						
Annual Fld.(Hazen)		163,000	205,000	316,000	367,000	
Annual Fld.(Foster)		163,000	204,000	302,000	342,000	
Goodrich St. Line		169,000	210,000	307,000	350,000	
Fuller's Formula		192,000	221,000	290,000	320,000	
Pettis' Formula					405,000	
Tennessee River at Chattanooga, Tennessee						Factor = 1.10
Daily Flow	250,000	305,000	328,000	363,000	380,000	419,000
Flood Events	184,000	258,000	286,000	350,000	375,000	412,000
Events per Century	184,000	258,000	285,000	350,000	375,000	412,000
Monthly Flood	185,000	270,000	295,000	348,000	365,000	401,000
Annual Fld.(Hazen)		256,000	287,000	338,000	361,000	397,000
Annual Fld.(Foster)		256,000	287,000	338,000	361,000	397,000
Goodrich St. Line		264,000	295,000	342,500	363,000	399,000
Fuller's Formula		321,000	370,000	485,000	535,000	589,000
Pettis' Formula						510,000
Yadkin River at Salisbury, North Carolina						Factor = 1.18
Daily Flow	51,000	79,000	93,000	135,000	160,000	188,500
Flood Event	40,000	73,000	90,000	133,000	155,000	182,500
Events per Century	39,500	73,000	88,000	130,000	155,000	182,500
Monthly Flood	40,000	73,000	89,000	130,000	150,000	176,500
Annual Fld.(Hazen)		72,500	87,000	119,000	133,000	156,500
Annual Fld.(Foster)		72,500	86,000	116,000	130,000	153,000
Goodrich St. Line		72,500	87,500	122,000	133,000	156,500
Fuller's Formula		84,500	97,500	128,000	141,000	166,000
Pettis' Formula						202,500

In this table, the results of the different statistical methods appear in some cases to be very nearly the same, though they are of different significance. Theoretically, if a series of flood data is arranged and

1. Data at this station not available in form to permit analysis by Daily and Monthly Flood methods. All values are peak flows.

plotted by the annual flood method, a given flow will be equaled or exceeded as an annual flood, once in a certain number of years, as T, on the average. However, this flood will have been reached as a peak, as a monthly flood, or as a daily flood, with a frequency greater than once in T years.

If the record at the same station is arranged and plotted by the Daily Flow method, a given flow will be equaled or exceeded as a daily flow once in a certain number of years, as T_1 on the average. This flow is likely to be equaled or exceeded as an annual flood, a monthly flood, or as a flood peak, with a frequency of less than once in T_1 years.

If the record of this station be analysed by the monthly flood method, a given flow will be equaled or exceeded as a monthly flow once in a certain number of years, as T_2, on the average. This flow will probably have been reached as a daily flow with a frequency greater than once in T_2 years, and as an annual flood with a frequency less than once in T_2 years, and as a flood peak with a frequency of about (it may be slightly more or less) once in T_2 years.

If this same record be plotted by the flood event method, a given flow will be equaled or exceeded as a peak flow once in a certain number of years, as T_3, on the average. It will have been reached probably as a daily flow with a frequency greater than once in T_3 years, as an annual flood with a frequency less than once in T_3 years, and as a monthly flood with a frequency of approximately (either slightly more or less) once in T_3 years.

Thus, for a given frequency, as once in Y years, theoretically the daily flow method should give the largest value of discharge, the monthly flood, and the flood event method, next, with values usually about the same, and the annual flood method the smallest value.

If Table VIII, above, is examined, it will be found that this order obtains in all cases, and that the differences are more apparent for smaller flows (i.e., for short time intervals). This is accounted for by the fact that the higher flows are relatively infrequent, and appear in the statistical arrays for all the methods of analysis.

The Goodrich method is just another way of plotting the annual flood data. It's significance is the same, and should give essentially the same results as that method.

The Flood Events per Century, or Modified California method, is the Flood Event method expressed in another form and shows the same tendencies. It's results are the same, or very nearly the same, as the Flood Event method.

The Fuller Formula checks the Annual Flood method (Hazen) within 15 per cent or less in seven out of ten stations for a frequency of 100 years. The remaining three stations, Nashville, Chattanooga, and Ferguson, differ by + 54 per cent, + 48 per cent, and -35 per cent, respectively, from the results of the Annual Flood method. This may be accounted for in this way: The Fuller Formula, in effect, gives the average relation (for a large number of rivers) of the size of infrequent floods to the average flood. In any river where the coefficient of variation differs greatly from the average coefficient of a large number of streams, the formula will be considerably in error. This is exactly what occurs in the cases mentioned above.

The Pettis Formula checks the maximum probable discharge by the Daily Flow method within 22 per cent or less for six cases out of ten. Of the remainder, Woodbury, Macon, and Fraley's Ferry, vary from the Daily Flow method by 218 per cent, 86 per cent, and 36 per cent, respectively. It appears significant that these three stations discharge the drainage of very similar watersheds, as concerns topography, physiography, and location, and would seem that the value of C, by further study, might be revised so as to vary for different types of terrain. In view of the fact that no physical data on the stream in question are required for this formula, its results are considered, on the whole, very satisfactory.

CONCLUSIONS

Eight methods and formulas for analysing flood frequencies have been reviewed, varying in basic data required and in significance and accuracy of results obtained.

Of course, when a record of at least twenty years, or longer is a vailable at a station where a knowledge of flood frequencies is desired, a method based on some statistical array will give the more dependable results. The Annual, Monthly, and Daily Flood Methods, and the Goodrich Straight Line Method are susceptible of treatment as equally spaced time series, varying only in the number of terms; when so treated, the points may be fitted with a frequency curve (except the Goodrich Method) as developed by Hazen and Foster. The Flood Event, and the Modified California Method, not being equally spaced time series, cannot be fitted with a computed frequency curve; the method of drawing in the curve to fit these data is entirely graphical.

In analysis by the Annual Flood Method, the advantage of determining the coefficient of variation, and of skew, is the certainty of treating the plotted data for a number of stations in the same manner; when one station only is studied this computation might be omitted, relying on drawing a representative curve by eye. However, it is believed that the aid to drawing the curve, even though only one station is under study, is well worth the time required to compute the coefficient of variation and of skew. As to the choice between the Logarithmic Probability Curve by Hazen, and Foster's Type III Curve, the results vary so slightly within the limits of the record, that either one may be used with the same degree of confidence, and choice may be left to the personal inclination of the designer. However, the writer agrees with Mr. Hazen to the effect that as the Logarithmic Probability Curve will give higher values for small frequencies (e.g., 100 year and 1,000 year) than the Foster Curve, that its use is preferable; this view is strengthened by the fact that the annual flood for any given frequency, is smaller than the flood peak or the daily flood for the same frequency.

The Goodrich Method provides an ingenious method of treating the Annual Flood basic data. It is purely graphical, and is perhaps slightly less laborious than the Hazen or Foster methods. Its results are essentially the same as that of the Hazen and Foster methods.

The Monthly Flood Method, in the writer's opinion, has no particular merit, and one of the other methods will show more nearly what is desired for engineering practice.

Since for any structure placed in, or across a river, the maximum instantaneous value of flood (except for surface storage) must be passed, the theoretically correct analysis is the Daily Flow Method, which gives the value of daily flow that is likely to be equaled or exceeded. When this method is used, as only a small percentage of the record is of interest, usually less than three per cent, due to the saving in time required to make the analysis, it will be usually preferable to take flows above some basic stage, which will give a number of points corresponding to about three per cent of the total record. When this is done, the curve must be drawn graphically. The Daily Flow Method has the disadvantage that the process of analysis requires more time than the other methods.

The Flood Event, and the Modified California Method, give frequencies of flood peaks in terms of flood events, and their significance is very different from the frequency of daily flows above some basic stage. For engineering practice, either of these methods will usually give results more nearly approaching those desired than the Annual or Daily Flood Methods. A great advantage of the Flood Event Method is that a much longer record suitable to this method may be available at a given station than for any other method of analysis. For example, the high water marks of large floods occurring before the systematic recording of streamflow records was begun, have, in many localities, been preserved. At many points, a complete record of such "high water marks" are available for a considerable period of years. Where the river control is stable, these gage heights may be translated into discharge, and in the present period of the difficulty of short term records, the value of the Flood Event Method is further enhanced.

As concerns flood flow formulas, of the great number which have been proposed, many of which are applicable to limited localities, two of those considered most dependable have been studied. In the Fuller Formula, as in many others, the most difficult thing is the determination of the value of C. The best method of determination involves the mean flood; the objection may be raised that if a record of sufficient length to define the average flood is available, then the record is also long enough to provide a statistical array for preparing a frequency curve. This may be true in some cases, but even then the Fuller Formula provides an approximate check on the statistical process, which in a short record, may be considerably in error.

The Pettis Formula has the advantage that all factors are determined by a definite procedure. In the writer's opinion, this formula is superior to any previously proposed. It takes advantage of rainfall records to supply the "weather variable," and rainfall records in this country are far more complete and longer than records of streamflow. On the other hand, as exemplified by this study, it appears that by extensive comparison, the constant, used as 328 for the entire eastern United States, might be varied for different localities or sections of the country, depending on topography and physical characteristics of the different drainage areas. True, the Pettis Formula does not give values for a number of different time intervals, but it does give a fair idea of the maximum probable 100 year discharge, which is the minimum for use in design of important hydraulic structures.

In all flood analysis, it should be borne in mind that the results, though they may appear definite, are no more accurate than the data on which they are based. The shortness of the records is the real handicap; however, this defect is slowly but surely being corrected with the passing years, as records of flow are being accumulated.

Where a record of a stream is available for twenty years or more, the correct use of any of the statistical methods outlined in this paper should give fairly accurate results; or lacking any streamflow record at all, the Pettis Width Formula, if intelligently applied, will furnish an approximate value of extreme discharge. In any event, the results must not be considered as a precise forecast of future conditions, but merely as a valuable aid to engineering judgment.

APPENDIX I

The following works have been consulted in the preparation of this paper:

1. Transactions, Am. Soc. C. E. Vol. 77 (1914).
2. " " " " " Vol. 87 (1924).
3. " " " " " Vol. 89 (1926).
4. " " " " " Vol. 91 (1927).
5. Preliminary Draft of a Manual for Analysis of Flood Flows, by the Mississippi Valley Committee, in collaboration with the U. S. Geological Survey. 1934.
6. Flood Flows, by Allen Hazen. 1930.
7. A New Theory of River Flood Flow, by Major C. R. Pettis. 1927.
8. Hydroelectric Handbook, by Creager and Justin. 1927.
9. Technical Reports, Miami Conservancy District, Arthur E. Morgan, Chief Engineer. 1920.
10. Numerous articles published in -

    Engineering News-Record,

    Civil Engineering,

    The Military Engineer.

Records of floods were taken from:

1. Water Supply Papers of the U. S. Geological Survey.
2. Record of Daily River Stages, by the U. S. Weather Bureau.
3. Water Resources of Tennessee. 1925.
4. Water Resources of Georgia, B. M. and M. R. Hall. 1907 (Water Supply Paper No. 197.)
5. Discharge Records in files of U. S. Engineer Office, Savannah, Georgia.

APPENDIX II

Logarithmic Skew Curve Factors [1]

Multiply Coefficient of Variation by These and Add or Subtract from the Mean.

Coefficient of Skew	Terms over mean, per cent	Per cent of term above limit 99 −	95 −	80 −	50 −	20 +	5 +	1 +	0.0 +	0.01 +	Corresponding Coefficient Variation
0.5	46.9	1.99	1.50	0.85	0.08	0.82	1.79	2.72	3.90	5.00	0.16
0.6	46.3	1.92	1.47	0.85	0.09	0.81	1.81	2.80	4.08	5.30	0.20
0.7	45.6	1.86	1.44	0.85	0.11	0.80	1.84	2.89	4.28	5.64	0.23
0.8	45.0	1.80	1.41	0.85	0.12	0.79	1.86	2.97	4.48	6.00	0.27
0.9	44.4	1.73	1.38	0.85	0.14	0.77	1.88	3.06	4.69	6.37	0.30
1.0	43.7	1.68	1.34	0.84	0.15	0.76	1.90	3.15	4.92	6.77	0.33
1.1	43.1	1.62	1.31	0.84	0.17	0.75	1.92	3.24	5.16	7.23	0.37
1.2	42.5	1.56	1.28	0.83	0.18	0.74	1.94	3.33	5.40	7.66	0.41
1.3	41.9	1.51	1.25	0.83	0.19	0.72	1.96	3.41	5.64	8.16	0.44
1.4	41.3	1.46	1.42	0.82	0.20	0.71	1.98	3.50	5.91	8.66	0.48
1.5	40.7	1.41	1.19	0.81	0.22	0.69	1.99	3.59	6.18	9.16	0.51
1.6	40.1	1.36	1.16	0.81	0.23	0.67	2.01	3.69	6.48	9.79	0.55
1.7	39.5	1.32	1.13	0.80	0.24	0.66	2.02	3.78	6.77		0.59
1.8	38.9	1.27	1.10	0.79	0.25	0.64	2.03	3.88	7.09		0.62
1.9	38.3	1.23	1.07	0.78	0.26	0.62	2.04	3.98	7.42		0.66
2.0	37.7	1.19	1.05	0.77	0.27	0.61	2.05	4.07	7.78		0.70
2.1	37.1	1.15	1.02	0.76	0.28	0.59	2.06	4.17	8.13		0.74
2.2	36.5	1.11	0.99	0.75	0.29	0.57	2.07	4.27	8.54		0.78
2.3	35.9	1.07	0.96	0.74	0.30	0.55	2.07	4.37	8.95		0.82
2.4	35.3	1.03	0.94	0.73	0.31	0.53	2.08	4.48	9.35		0.86
2.5	34.7	1.00	0.91	0.72	0.31	0.51	2.08	4.58	9.75		0.90
2.6	34.1	0.97	0.89	0.71	0.32	0.49	2.09	4.68			0.94
2.7	33.5	0.94	0.86	0.69	0.33	0.47	2.09	4.78			0.98
2.8	32.9	0.91	0.84	0.68	0.33	0.45	2.09	4.89			1.03
2.9	32.3	0.87	0.82	0.67	0.34	0.43	2.09	5.01			1.08

Adjusted Skew = Computed Skew $(1 + \frac{8.5}{n})$

The figures in the last column show the value of the coefficient of variation that, in connection with the coefficient of skew shown in the first column, will produce plotting point of a line that is straight on log. probability paper.

1. Reproduced from page 188, Flood Flows, Allen Hazen, 1930.

Foster's Skew Curve Factors, Type III [2]

Multiply Coefficient of Variation by These and Add or Subtract from the Mean.

Coefficient of Skew	Terms over Mean, per cent	Per cent of terms above limit									Corresponding Coefficient Variation
		99 -	95 -	80 -	50 -	20 +	5 +	1 +	0.1 +	0.01 +	
0	50.0	2.33	1.64	0.84	0	0.84	1.64	2.33	3.09	3.73	
0.2	48.7	2.18	1.58	0.85	0.03	0.83	1.69	2.48	3.38	4.16	
0.4	47.3	2.03	1.51	0.85	0.06	0.82	1.74	2.62	3.67	4.60	
0.6	46.0	1.88	1.45	0.86	0.09	0.80	1.79	2.77	3.96	5.04	
0.8	44.7	1.74	1.38	0.86	0.13	0.78	1.83	2.90	4.25	5.48	
1.0	43.3	1.59	1.31	0.86	0.16	0.76	1.87	3.03	4.54	5.92	
1.2	42.0	1.45	1.25	0.85	0.19	0.74	1.90	3.15	4.82	6.37	
1.4	40.7	1.32	1.18	0.84	0.22	0.71	1.93	3.28	5.11	6.82	
1.6	39.4	1.19	1.11	0.82	0.25	0.68	1.96	3.40	5.39	7.28	
1.8	38.1	1.08	1.03	0.80	0.28	0.64	1.98	3.50	5.66	7.75	
2.0	36.8	0.99	0.95	0.78	0.31	0.61	2.00	3.60	5.91	8.21	
2.2	35.5	0.90	0.89	0.75	0.33	0.58	2.01	3.70	6.20		
2.4	34.3	0.83	0.82	0.71	0.35	0.54	2.01	3.78	6.47		
2.6	33.0	0.74	0.76	0.68	0.37	0.51	2.01	3.87	6.73		
2.8	31.9	0.71	0.71	0.65	0.38	0.47	2.02	3.95	6.99		
3.0	30.8	0.67	0.66	0.62	0.40	0.42	2.02	4.02	7.25		

$$\text{Adjusted Skew} = \text{Computed Skew}\left(1 + \frac{8.5}{n}\right)$$

2. Reproduced from Trans. Am. Soc. C. E. Vol. 87, pp. 162 and 199.

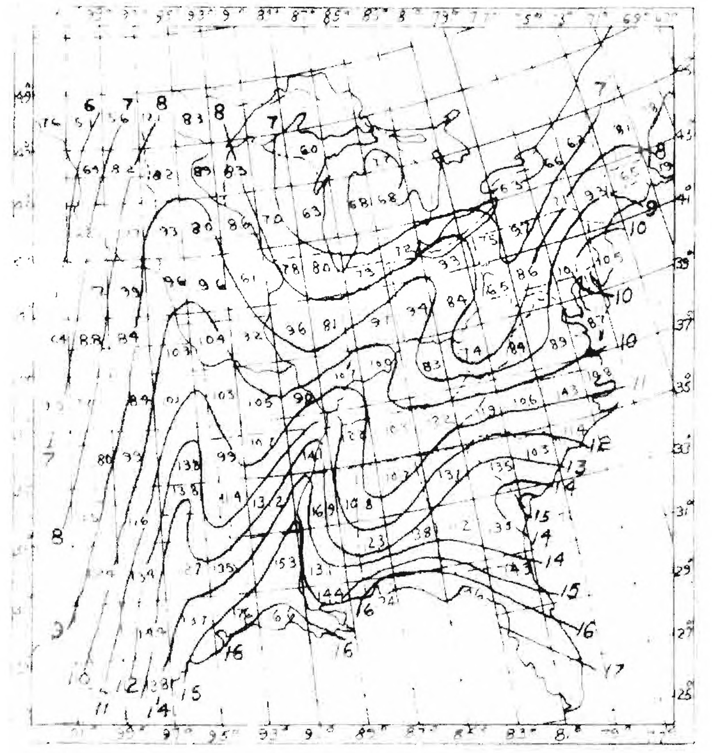
Spacing of Ordinates for Skew Frequency Paper, by R. D. Goodrich [3]

t = percentage of time.

x = distance from origin for skew frequency ruling.

t	+ x	t	-x	t	-x	t	-x
99.99	0.602	90	0.000	50	0.521	10	1.339
99.98	0.568	88	0.036	48	0.547	9	1.387
99.95	0.519	86	0.068	46	0.573	8	1.441
99.9	0.477	84	0.099	44	0.599	7	1.501
99.8	0.431	82	0.128	42	0.626	6	1.571
99.6	0.380	80	0.156	40	0.654	5	1.652
99.4	0.347	78	0.182	38	0.683	4.5	1.699
99.2	0.322	76	0.208	36	0.713	4	1.751
99	0.301	74	0.233	34	0.744	3.5	1.811
98	0.230	72	0.251	32	0.776	3	1.878
97	0.183	70	0.282	30	0.810	2.5	1.959
96	0.146	68	0.305	28	0.846	2.0	2.057
95	0.114	66	0.329	26	0.883	1.8	2.103
94	0.087	64	0.353	24	0.924	1.6	2.155
93	0.063	62	0.376	22	0.967	1.4	2.213
92	0.040	60	0.400	20	1.014	1.2	2.281
91	0.020	58	0.424	18	1.064	1.0	2.361
90	0.000	56	0.448	16	1.121	0.9	2.406
		54	0.472	14	1.184	0.8	2.457
		52	0.496	12	1.256	0.7	2.516

3. Reproduced from Trans. Am. Soc. C. E. Vol. 91, p. 13.



ISOPLUVIAL CHART FOR 100 YEAR PERIOD AND 6 DAY RAINFALL, EASTERN UNITED STATES

FOR USE IN THE PETTIS WIDTH FORMULA

... Technical Reports of ...
... Conservancy District, Part V

APPENDIX III

Tabulated computations for analysis by every method studied in this paper, are given for all stations studied, except the Chattahoochee River at West Point, Georgia, Computations for which were given in the body of the paper.

1. Cumberland River at Nashville, Tennessee.

Cumberland River at Nashville, Tennessee. Annual Flood Computations. 44 year record. October 1887 - September 1931.

Year	Maximum Daily Disch. c.f.s.	Disch. in Order of Size	Plotting Position	In Terms of Mean	Difference from 1	Difference Squared	Cube of Difference +	Cube of Difference -
1887-88	112,000	203,000	1.14	1.741	0.741	0.551	0.409	
1888-89	99,900	159,000	3.41	1.365	.365	.134	.488	
1889-90	154,000	159,000	5.68	1.365	.365	.134	.488	
1890-91	148,000	154,000	7.95	1.322	.322	.104	.335	
1891-92	111,000	153,000	10.22	1.312	.312	.097	.031	
1892-93	118,000	148,000	12.50	1.270	.270	.073	.020	
1893-94	122,000	147,000	14.78	1.262	.262	.069	.018	
1894-95	84,800	144,000	17.04	1.235	.235	.055	.013	
1895-96	125,000	140,000	19.30	1.203	.203	.041	.008	
1896-97	147,000	137,000	21.55	1.176	.176	.031	.005	
1897-98	110,000	137,000	23.85	1.176	.176	.031	.005	
1898-99	117,000	134,000	26.10	1.150	.150	.022	.003	
1899-90	65,300	125,000	28.40	1.072	.072	.005	0	
1900-01	114,000	124,000	30.65	1.065	.065	.004	0	
1901-02	137,000	122,000	32.90	1.048	.048	.002	0	
1902-03	116,000	122,000	35.20	1.048	.048	.002	0	
1903-04	106,000	122,000	37.50	1.048	.048	.002	0	
1904-05	80,400	120,000	39.75	1.030	.030	.001	0	
1905-06	92,600	120,000	42.00	1.030	.030	.001	0	
1906-07	111,000	118,000	44.30	1.012	.012	0	0	
1907-08	72,400	117,000	46.60	1.004	.004	0	0	
1908-09	116,000	116,000	48.90	.995	.005	0		0
1909-10	95,000	116,000	51.10	.995	.005	0		0
1910-11	110,000	114,000	53,50	.978	.022	0		0
1911-12	144,000	112,000	55.60	.960	.040	.002		0
1912-13	153,000	111,000	58.0	.953	.047	.002		0
1913-14	101,000	111,000	60.2	.953	.047	.002		0
1914-15	107,000	110,000	62.5	.944	.056	.003		0
1915-16	122,000	110,000	64.8	.944	.056	.003		0
1916-17	140,000	107,000	67.0	.918	.082	.007		.001
1917-18	159,000	106,000	69.4	.909	.091	.008		.001
1918-19	137,000	101,000	71.5	.866	.134	.018		.002
1919-20	134,000	99,900	73.9	.856	.144	.021		.003
1920-21	86,400	95,100	76.1	.816	.184	.034		.006
1921-22	120,000	92,600	78.5	.795	.205	.042		.009
1922-23	122,000	89,300	80.6	.766	.234	.055		.013
1923-24	124,000	86,500	83.0	.742	.258	.067		.017
1924-25	86,500	86,400	85.3	.740	.260	.068		.017
1925-26	89,300	84,800	87.5	.727	.273	.075		.020
1926-27	203,000	80,400	89.9	.689	.311	.097		.030
1927-28	120,000	79,200	92.0	.680	.320	.102		.033
1928-29	159,000	73,400	94.4	.629	.371	.138		.051

Cumberland River at Nashville, Tennessee. Annual Flood Method (contd.).

Year	Maximum Daily Disch. c.f.s.	Disch. in Order of Size	Plotting Position	In Terms of Mean	Difference from 1	Difference Squared	Cube of Difference +	Cube of Difference -
1929-30	79,200	72,400	96.6	.620	.380	.144		.055
1930-31	73,400	65,300	98.8	.560	.440	.194		.085
Total		5,124,300		43.970		2.441	1.823	0.343
Mean		116,460						

$$\text{Coefficient of Variation} = \sqrt{\frac{2.441}{44 - 1}} = 0.238$$

$$\text{Coefficient of Skew (comp.)} = \frac{1.823 - 0.343}{(44 - 1)(0.238)^3} = 2.55$$

$$\text{Coefficient of Skew (adj.)} = 2.55 \times 1.193 = 3.05.$$

Cumberland River at Nashville, Tennessee. Goodrich Straight Line Method. Tabulated data. 44 year record. October 1887 - September, 1931.

R = discharge arranged in order of magnitude. c.f.s.	Per cent time for plotting.	R in terms of mean.	R - 0.5
65,300	1.14	0.560	0.060
72,400	3.41	.620	.120
73,400	5.68	.629	.129
79,200	7.95	.680	.180
80,400	10.22	.689	.189
84,800	12.50	.727	.227
86,400	14.78	.740	.240
86,500	17.04	.742	.242
89,300	19.30	.766	.266
92,600	21.55	.795	.295
95,100	23.85	.816	.316
99,900	26.10	.856	.356
101,000	28.40	.866	.366
106,000	30.65	.909	.409
107,000	32.90	.918	.418
110,000	35.20	.944	.444
110,000	37.50	.944	.444
111,000	39.75	.953	.453
111,000	42.00	.953	.453
112,000	44.3	.960	.460
114,000	46.6	.978	.478
116,000	48.9	.995	.495
116,000	51.1	.995	.495
117,000	53.5	1.004	.504
118,000	55.6	1.012	.512
120,000	58.0	1.030	.530
120,000	60.2	1.030	.530
122,000	62.5	1.048	.548
122,000	64.8	1.048	.548
122,000	67.0	1.048	.548
124,000	69.4	1.065	.565
125,000	71.5	1.072	.572
134,000	73.9	1.150	.650
137,000	76.1	1.176	.676
137,000	78.5	1.176	.676
140,000	80.6	1.203	.703
144,000	83.0	1.235	.735
147,000	85.3	1.262	.762
148,000	87.5	1.270	.770
153,000	89.9	1.312	.812
154,000	92.0	1.322	.822
159,000	94.4	1.365	.865
159,000	96.6	1.365	.865
203,000	98.8	1.741	1.241

Cumberland River at Nashville, Tennessee. Monthly Flood method.
44 year record. October 1887 - September 1931.
(Flows above 90,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
203,000		1	0.0949
200,000		2	.274
159,000	2	4	.569
154,000	2	6	.949
153,000		7	1.232
148,000		8	1.421
147,000		9	1.612
144,000		10	1.802
142,000		11	1.990
140,000		12	2.180
137,000	3	15	2.560
135,000		16	2.940
134,000		17	3.130
131,000		18	3.32
129,000		19	3.51
128,000	2	21	3.79
127,000		22	4.08
125,000	2	24	4.36
124,000		25	4.65
123,000		26	4.84
122,000	4	30	5.31
120,000	3	33	5.97
119,000		34	6.35
118,000	2	36	6.64
117,000		37	6.91
116,000	4	41	7.40
115,000	2	43	7.96
114,000	3	46	8.44
112,000		47	8.81
111,000	3	50	9.20
110,000	2	52	9.66
109,000	2	54	10.05
107,000	3	57	10.52
106,000	7	64	11.67
103,000		65	12.22
101,000	2	67	12.50
100,000-98,000	2	69	12.90
98,000-96,000	5	74	13.58
96,000-94,000	4	78	14.40
94,000-92,000	2	80	14.99
92,000-90,000	5	85	15.62

$n = 44 \times 12 = 528.$

Cumberland River at Nashville, Tennessee. Daily Flow method.
44 Year record. October, 1887 - September, 1931.
(Flows above 100,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
203,000		1	0.00312
200,000	2	3	.0125
197,000		4	.0218
192,000		5	.0280
183,000		6	.0342
180,000		7	.0405
166,000		8	.0467
164,000		9	.0529
160,000		10	.0591
159,000	2	12	.0685
158,000	2	14	.0810
157,000		15	.0904
156,000		16	.0966
154,000	4	20	.112
153,000	3	23	.134
152,000	3	26	.153
150,000	4	30	.175
148,000	5	35	.202
147,000	3	38	.228
146,000	4	42	.249
145,000		43	.254
144,000	4	47	.280
143,000	4	51	.305
142,000	3	54	.327
140,000	10	64	.368
138,000	6	70	.417
137,000	11	81	.470
136,000	5	86	.520
135,000		87	.539
134,000	6	93	.560
133,000	4	97	.591
132,000	5	102	.620
131,000	3	105	.645
130,000	3	108	.664
129,000	2	110	.679
128,000	8	118	.710
127,000	4	122	.748
126,000	2	124	.765
125,000	8	132	.796
124,000	7	139	.844
123,000	6	145	.885
122,000	12	157	.940
121,000	7	164	1.000
120,000	7	171	1.044
120,000-115,000	61	232	1.252
115,000-110,000	75	307	1.680
110,000-105,000	88	395	2.185
105,000-100,000	57	452	2.635

$n = 44 \times 365 = 16,060$

Cumberland River at Nashville, Tennessee. Flood Event and Modified California Methods. 44 Year record. October, 1887 - September, 1931. (Flows above 90,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California Method. Average number of events per century = 181.9 x per cent of flood peaks.
203,000		1	0.625	1.14
159,000	2	3	2.50	4.55
154,000		4	4.38	7.95
153,000		5	5.62	10.22
148,000		6	6.88	12.50
147,000		7	8.13	14.80
144,000		8	9.37	17.05
140,000		9	10.62	19.30
138,000		10	11.88	21.6
137,000	3	13	14.38	26.1
134,000		14	16.88	30.7
129,000		15	18.12	33.0
127,000		16	19.38	35.2
125,000	2	18	21.2	38.5
124,000		19	23.1	42.0
123,000		20	24.4	44.4
122,000	3	23	26.85	48.8
120,000	2	25	30.0	54.5
119,000	2	27	32.5	59.1
118,000	3	30	35.5	64.5
117,000		31	38.1	69.2
116,000	5	36	41.9	76.0
115,000		37	45.6	83.0
114,000	3	40	48.1	87.5
113,000		41	50.6	92.0
112,000		42	51.9	94.2
111,000	2	44	53.7	97.5
110,000	2	46	56.2	102.2
109,000	3	49	59.4	108.0
108,000		50	61.9	112.3
107,000	3	53	64.4	117.0
106,000	6	59	70.0	127.2
104,000		60	74.4	135.0
101,000	2	62	76.1	138.5
100,000-98,000	4	66	80.0	145.5
98,000-96,000	5	71	85.6	155.8
96,000-94,000	3	74	90.5	164.5
94,000-92,000		75	93.5	169.0
92,000-90,000	5	80	96.9	176.0

n = 80 flood peaks.

Average number of events per century = $\frac{(80)100}{44}$ = 181.9

Cumberland River at Nashville, Tennessee. The Fuller Formula.

$$Q = C\,A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 12,860 square miles.

$A^{0.8}$ = 1,950

Ave. Q = 116,460

$$C = \frac{116,460}{1,950} = 60$$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	60	1,950	1.60	2.60	304,000
50			1.36	2.36	276,000
10			0.80	1.80	210,000
5			0.56	1.56	182,000

Cumberland River at Nashville, Tennessee. The Pettis Formula.

$$Q = 328\,P\,W^{5/4}$$

Drainage area = 12,860 square miles.

Length of River = 450 miles (scaled from map)

Then $W = \frac{12,860}{450} = 28.6$

and $W^{5/4} = 66.0$

From Plate 6, following page 51, P is found to be 10 inches.

Then $Q = 328 \times 10 \times 66.0 = 217,000$ c.f.s.

2. Flint River near Woodbury, Georgia.

Flint River near Woodbury, Georgia. Annual Flood computations. 22 year record. October 1900 - September 1922.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size.	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1900-01	18,250	36,900	2.27	2.090	1.090	1.188	1.295	
1901-02	28,700	31,300	6.82	1.772	.772	.597	.460	
1902-03	25,800	28,700	11.36	1.625	.625	.390	.244	
1903-04	15,000	26,300	15.91	1.490	.490	.240	.117	
1904-05	9,100	25,800	20.45	1.460	.460	.211	.098	
1905-06	12,800	25,000	25.00	1.415	.415	.172	.072	
1906-07	4,800	23,700	29.55	1.342	.342	.117	.040	
1907-08	16,200	19,200	34.09	1.088	.088	.008	.001	
1908-09	19,200	18,600	38.64	1.053	.053	.003	0	
1909-10	8,450	18,300	43.18	1.037	.037	.001	0	
1910-11	5,820	18,250	47.73	1.033	.033	.001	0	
1911-12	26,300	17,800	52.27	1.009	.009	0	0	
1912-13	31,300	16,200	58.82	.918	.082	.007		.001
1913-14	6,200	15,000	61.36	.850	.150	.023		.003
1914-15	10,700	12,800	65.91	.725	.275	.075		.021
1915-16	25,000	10,700	70.45	.606	.394	.156		.061
1916-17	17,800	9,100	75.00	.515	.485	.235		.114
1917-18	8,320	8,450	79.55	.479	.521	.272		.142
1918-19	18,600	8,320	84.09	.471	.529	.279		.147
1919-20	39,900	6,200	88.64	.352	.648	.420		.271
1920-21	18,300	5,820	93.18	.330	.670	.449		.300
1921-22	23,700	4,800	97.73	.272	.728	.530		.385
Total	388,740			21.932		5.374	2.327	1.455
Mean	17,670							

Coefficient of Variation $= \sqrt{\dfrac{5.374}{22 - 1}} = 0.506$

Coefficient of Skew (comp.) $= \dfrac{2.327 - 1.445}{(22 - 1)(.506)^3} = 0.323$

Coefficient of Skew (adj.) $= 0.323 \times 1.386 = 0.448$

Flint River near Woodbury, Georgia. Goodrich Straight Line Method.
Tabulated data. 22 year record. October, 1900 - September, 1922.

R = discharge arranged in order of magnitude c.f.s.	Per cent time for plotting.	R in terms of mean	R - 0.0
4,800	2.27	0.272	
5,820	6.82	.330	
6,200	11.36	.352	
8,320	15.59	.471	
8,450	20.45	.471	
9,100	25.00	.515	
10,700	29.55	.606	
12,800	34.09	.725	
15,000	38.64	.850	
16,200	43.18	.918	
17,800	47.73	1.009	
18,250	52.27	1.003	
18,300	56.82	1.037	
18,600	61.36	1.053	
19,200	65.91	1.088	
23,700	70.45	1.342	
25,000	75.00	1.415	
25,800	79.55	1.460	
26,300	84.09	1.490	
28,700	88.64	1.625	
31,300	93.18	1.772	
36,900	97.73	2.090	

When these points are plotted on skew frequency paper, they define a straight line, so that the constant "a" which is added or subtracted from "R" to give points on a straight line is zero.

Flint River near Woodbury, Georgia. Monthly Flood method.
22 year record. October 1900 - September, 1922.
(Flows above 10,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
36,900		1	0.189
31,300		2	.569
28,700		3	.947
26,300		4	1.325
25,800		5	1.705
25,000		6	2.08
23,700		7	2.46
21,100		8	2.84
19,200		9	3.22
19,000		10	3.60
18,600		11	3.98
18,300	2	13	4.55
18,250		14	5.11
17,800		15	5.49
16,800		16	5.86
16,600		17	6.25
16,200		18	6.63
15,200		19	7.00
15,000		20	7.39
14,700		21	7.76
14,200		22	8.15
14,000		23	8.51
13,800	2	25	9.09
13,300	3	28	10.02
13,000	2	30	10.99
12,800		31	11.53
12,300		32	11.92
12,100		33	12.30
11,400		34	12.70
11,100		35	13.05
10,700		36	13.45
10,400		37	13.80
10,300		38	14.20

$n = 12 \times 22 = 264.$

Flint River near Woodbury, Georgia. Daily Flow method.
22 year record. October, 1900 - September, 1922.
(Flows above 1,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
36,900		1	0.006
34,500		2	.019
31,300		3	.031
28,700		4	.044
27,900		5	.056
27,700		6	.069
26,300		7	.081
25,800		8	.093
25,700		9	.106
25,000		10	.118
24,400		11	.131
23,700		12	.143
23,400		13	.156
22,600		14	.168
22,100		15	.181
21,100		16	.193
20,800		17	.205
20,300		18	.218
19,600		19	.230
19,200		20	.242
19,100		21	.255
19,000	2	23	.274
18,600		24	.293
18,300	5	29	.330
18,250		30	.367
18,000		31	.380
17,800		32	.392
17,500		33	.405
17,000	4	37	.436
16,800	2	39	.474
16,600		40	.492
16,500		41	.504
16,200	2	43	.511
16,100		44	.541
15,800	4	48	.573
15,500		49	.605
15,200	3	52	.630
15,000	2	54	.660
15,000-14,000	13	67	.753
14,000-13,000	18	85	.946
13,000-12,000	12	97	1.132
12,000-11,000	12	109	1.281
11,000-10,000	19	128	1.475

n = 365 x 22 = 8040

Flint River near Woodbury, Georgia. Flood Event and Modified California methods. 22 year record. October 1900 - September 1922. (Flows above 10,300 c.f.s.)

Flood Discharge	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California Method. Average number of events per century = 191.0 x per cent of flood peaks.
36,900		1	1.19	2.27
31,300		2	3.57	6.81
28,700		3	5.95	11.38
26,300		4	8.34	15.90
25,800		5	10.72	20.5
25,000		6	13.10	26.2
23,700		7	15.49	29.6
21,100		8	17.85	34.1
20,800		9	20.25	38.7
19,200		10	22.60	43.1
19,100		11	25.00	47.7
19,000		12	27.40	52.4
18,600		13	29.75	56.8
18,300	2	15	33.30	63.5
18,250		16	36.90	70.5
17,800		17	39.30	75.0
16,800		18	41.60	79.5
16,600		19	44.00	84.0
16,200		20	46.40	88.5
15,200	2	22	50.00	95.5
15,000		23	53.50	102.2
14,700		24	56.00	107.0
14,500		25	58.40	111.5
14,200		26	60.60	116.0
14,000		27	63.00	120.3
13,800	2	29	66.60	127.3
13,300	3	32	72.50	138.3
13,000		33	77.40	147.8
12,800		34	79.80	152.2
12,300		35	82.10	157.0
12,200		36	84.50	161.2
12,100		37	86.90	166.0
11,400		38	89.20	170.5
11,400		39	91.50	174.5
10,700		40	94.00	179.5
10,400		41	96.40	184.0
10,300		42	98.80	188.6

n = 42 flood peaks.

Average number of events per century = $\frac{(42)}{22}$ 100 = 191.0

Flint River near Woodbury, Georgia. The Fuller Formula.

$$Q = C A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 1,090 square miles.

$A^{0.8}$ = 269

Ave. Q = 17,670 c.f.s.

$$C = \frac{17,670}{269} = 70.$$

Interval in years T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	60	269	1.60	2.60	46,000
50			1.36	2.36	41,500
10			0.80	1.80	32,000
5			0.56	1.56	27,500

Flint River near Woodbury, Georgia. The Pettis Formula.

$$Q = 328\ P\ W^{5/4}$$

Drainage area = 1,090 square miles.

Length of river = 55 miles (scaled from amp.)

Then $W = \frac{1,090}{55} = 19.8$

and $W^{5/4} = 41.6$

From Plate 6, following page 51, P is found to be 13 inches.

Then Q = 328 x 13 x 41.6 = 178,000 c.f.s.

3. <u>Hiwassee River at Reliance, Tennessee.</u>

Hiwassee River at Reliance, Tennessee. Annual Flood computations.
32 year record. October, 1900 - September, 1932.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting Position	In Terms of Mean	Difference from 1	Difference Squared	Cube of Difference	
							+	-
1900-01	37,500	55,400	1.56	2.195	1.195	1.430	1.700	
1901-02	38,000	55,200	4.69	2.188	1.188	1.415	1.670	
1902-03	32,100	38,000	7.81	1.507	0.507	0.258	0.131	
1903-04	10,500	37,500	10.94	1.488	.488	.239	.116	
1904-05	22,700	36,500	14.06	1.449	.449	.201	.090	
1905-06	21,200	35,700	17.19	1.416	.416	.174	.072	
1906-07	55,200	35,500	20.31	1.408	.408	.167	.068	
1907-08	24,400	35,500	23.44	1.408	.408	.167	.068	
1908-09	36,500	33,000	26.56	1.309	.309	.096	.030	
1909-10	11,600	33,000	29.69	1.309	.309	.096	.030	
1910-11	18,500	32,100	32.81	1.272	.272	.074	.020	
1911-12	33,000	31,500	35.94	1.250	.250	.063	.016	
1912-13	29,500	29,500	39.06	1.170	.170	.029	.005	
1913-14	6,940	25,200	42.19	1.000	.0	.0	0	
1914-15	19,500	24,400	45.31	0.968	.032	.001		0
1915-16	35,500	22,700	48.44	.900	.100	.010		.001
1916-17	35,500	21,200	51.56	.841	.159	.025		.004
1917-18	17,500	21,000	54.69	.834	.166	.028		.005
1918-19	33,000	19,500	57.81	.774	.226	.051		.012
1919-20	55,400	18,500	60.94	.734	.266	.071		.019
1920-21	31,500	18,500	64.06	.734	.266	.071		.019
1921-22	35,700	17,700	67.19	.702	.298	.089		.027
1922-23	25,200	17,500	70.31	.694	.341	.116		.040
1924-25	10,700	16,400	76.56	.651	.349	.122		.043
1925-26	13,000	15,000	79.69	.595	.405	.164		.067
1926-27	16,600	13,000	82.81	.516	.484	.234		.113
1927-28	18,500	11,600	85.94	.460	.540	.292		.158
1928-29	21,000	11,400	89.06	.452	.548	.300		.165
1929-30	16,400	10,700	92.19	.424	.576	.332		.192
1930-31	11,400	10,500	95.31	.416	.584	.340		.198
1931-32	17,700	6,940	98.44	.275	.725	.528		.381
Total	806,700			31.998		7.277	4.016	1.473
Mean	25,209							

Coefficient of Variation $= \sqrt{\frac{7.277}{32 - 1}} = 0.485.$

Coefficient of Skew (comp.) $= \frac{4.016 - 1.473}{(32 - 1)(0.485)^3} = 0.720$

Coefficient of Skew (adj.) $= 0.720 \times 1.265 = 0.910$

Hiwassee River at Reliance, Tennessee. Goodrich Straight Line Method. Tabulated data.

R = discharge arranged in order of magnitude, c.f.s.	Per cent time for plotting.	R in terms of mean.	R - 0.20
6,940	1.56	0.275	0.075
10,500	4.69	.416	.216
10,700	7.81	.424	.224
11,400	10.94	.452	.252
11,600	14.06	.460	.260
13,000	17.19	.516	.316
15,000	20.31	.595	.395
16,400	23.44	.651	.451
16,600	26.56	.659	.459
17,500	29.69	.694	.495
17,700	32.81	.702	.502
18,500	35.94	.734	.534
18,500	39.06	.734	.534
19,500	42.19	.774	.574
21,000	45.31	.834	.634
21,200	48.44	.841	.641
22,700	51.56	.900	.700
24,400	54.69	.968	.768
25,200	57.81	1.000	.800
29,500	60.94	1.170	.970
31,500	64.06	1.250	1.050
32,100	67.19	1.272	1.072
33,000	70.31	1.309	1.109
33,000	73.44	1.309	1.109
35,500	76.56	1.408	1.208
35,500	79.69	1.408	1.208
35,700	82.81	1.416	1.216
36,500	85.94	1.449	1.249
37,500	89.06	1.488	1.288
38,000	92.19	1.507	1.307
55,200	95.31	2.188	1.988
55,400	98.44	2.195	1.995

Hiwassee River at Reliance, Tennessee. Monthly Flood method.
32 year record. October 1900 - September 1932.
(Flows above 10,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting $= \frac{100(m - 0.5g)}{n}$
55,400		1	0.131
55,200		2	.391
38,000		3	.657
37,500		4	.912
36,500		5	1.17
35,700		6	1.44
35,500	2	8	1.82
34,600		9	2.21
33,700		10	2.47
33,000	3	13	3.00
32,200		14	3.52
32,100		15	3.78
31,500		16	4.04
30,800		17	4.30
29,500		18	4.56
27,000		19	4.81
26,900		20	5.08
26,500		21	5.34
25,200		22	5.60
25,000	2	24	5.99
24,400		25	6.39
24,200		26	6.65
23,500		27	6.90
23,000		28	7.16
22,700		29	7.43
22,500		30	7.69
21,200		31	7.95
21,000		32	8.21
20,200		33	8.46
20,000		34	8.74
20,000-19,000	1	35	9.00
19,000-18,000	1	36	9.25
18,000-17,000	8	44	10.43
17,000-16,000	6	50	12.25
16,000-15,000	7	57	13.93
15,000-14,000	5	62	15.50
14,000-13,000	9	71	17.32
13,000-12,000	5	76	19.15
12,000-11,000	14	90	21.65
11,000-10,000	7	97	24.35

$n = 12 \times 32 = 384$

Hiwassee River at Reliance, Tennessee. Daily Flow method.
32 year record. October 1900 - September 1932.
(Flows above 10,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
55,400		1	0.00429
55,200		2	.0128
38,000		3	.021
37,500		4	.030
36,500		5	.039
35,700		6	.047
35,500	4	10	.069
34,600		11	.090
33,700		12	.099
33,000	3	15	.115
32,800		16	.133
32,200		17	.141
32,100		18	.150
32,000		19	.158
31,500		20	.167
30,800		21	.176
30,400		22	.184
29,500	2	24	.197
28,400		25	.210
27,000	3	28	.227
26,900		29	.244
26,500		30	.253
26,000		31	.261
25,500		32	.270
25,200	2	34	.283
25,000	3	37	.312
24,400		38	.321
24,200		39	.330
23,600		40	.338
23,500	2	42	.351
23,000		43	.364
22,700		44	.372
22,500	2	46	.385
22,000		47	.398
22,000-21,000	3	50	.415
21,000-20,000	4	54	.445
20,000-19,000	3	57	.475
19,000-18,000	6	53	.514
18,000-17,000	14	77	.599
17,000-16,000	18	95	.736
16,000-15,000	15	110	.878
15,000-14,000	14	124	1.002
14,000-13,000	22	146	1.154
13,000-12,000	26	172	1.360
12,000-11,000	45	217	1.663
11,000-10,000	37	254	2.015

n = 365 x 32 = 11,690.

Hiawassee River at Reliance, Tennessee. Flood Event and Modified California methods. 32 year record. Oct. 1900 - Sept. 1932. (Flows above 10,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks $= \frac{100(m - 0.5g)}{n}$	Modified California Method. Average number of events per century = 450 x per cent of flood peaks.
55,400		1	0.347	1.56
55,200		2	1.04	4.68
38,000		3	1.74	7.84
37,500		4	2.43	10.91
36,000		5	3.13	14.10
35,700		6	3.82	17.20
35,500	3	9	5.21	23.5
34,600		10	6.60	29.7
33,700		11	7.30	32.8
33,000	3	14	8.69	39.0
32,200		15	10.07	45.4
32,100		16	10.78	48.5
32,000		17	11.46	51.5
31,500		18	12.15	54.6
30,800		19	12.85	57.8
29,500	2	21	13,90	62.5
28,400		22	14.92	67.2
27,000		23	15.62	70.4
26,900		24	16.32	73.5
26,500		25	17.02	76.6
25,200	2	27	18.05	81.1
25,000	3	30	19.80	89.0
24,400		31	21.20	95.5
24,200		32	21.85	98.0
23,500		33	22.60	101.8
23,000		34	23.25	104.6
22,700		35	23.95	107.8
22,500		36	24.65	111.0
21,200		37	25.35	114.0
21,000		38	26.05	117.2
20,000		39	26.75	120.2
20,000-19,000	2	41	27.8	125.0
19,000-18,000	5	46	30.2	135.8
18,000-17,000	10	56	35.4	159.1
17,000-16,000	10	66	42.4	191.0
16,000-15,000	8	74	48.6	218.5
15,000-14,000	6	80	53.5	240.5
14,000-13,000	16	96	61.1	275.0
13,000-12,000	10	106	70.1	316.0
12,000-11,000	22	128	81.4	366.0
11,000-10,000	16	144	94.5	425.0

n = 144 flood peaks

Average number of events per century $= \frac{(144)100}{32} = 450$

Hiwassee River at Reliance, Tennessee. The Fuller Formula.

$$Q = C\,A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 1,180 square miles.

$A^{0.8} = 288$

Ave. $Q = 25,209$ c.f.s.

$C = \frac{25,209}{288} = 87.5$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	87.5	288	1.60	2.60	65,500
50			1.36	2.36	59,500
10			0.80	1.80	45,200
5			0.56	1.56	39,200

Hiwassee River at Reliance, Tennessee. The Pettis Formula.

$$Q = 328\,P\,W^{5/4}$$

Drainage area = 1,180 square miles.

Length of river = 77 miles (scaled from map).

Then $W = \frac{1,180}{77} = 15.32$

and $W^{5/4} = 30.25$

From Plate 6, following page 51, P is found to be 11 inches.

Then $Q = 328 \times 11 \times 30.25 = 109,000$ c.f.s.

4. Ocmulgee River at Macon, Georgia. Annual Flood computations.

Ocmulgee River at Macon, Georgia. Annual Flood computations.
37-year record. January 1895 - December 1931.

Year	Maximum Daily disch. c.f.s.	Disch. in order of size	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1895	31,800	68,500	1.35	2.355	1.355	1.835	2.490	
1896	39,000	49,600	4.05	1.705	0.705	0.496	0.350	
1897	30,500	47,000	6.76	1.615	.615	.379	.233	
1898	31,550	46,000	9.46	1.580	.580	.336	.195	
1899	22,260	43,000	12.16	1.475	.475	.225	.107	
1900	36,360	42,200	14.86	1.450	.450	.202	.091	
1901	24,020	42,000	17.57	1.442	.442	.196	.086	
1902	43,000	39,000	20.27	1.340	.342	.116	.040	
1903	31,680	36,400	22.97	1.250	.250	.063	.016	
1904	14,380	35,200	25.68	1.210	.210	.044	.009	
1905	19,500	32,000	28.38	1.100	.100	.010	.001	
1906	28,380	31,800	30.08	1.092	.092	.008	.0	
1907	16,320	31,700	33.78	1.089	.089	.008	0	
1908	29,120	31,600	36.49	1.085	.085	.007	0	
1909	30,380	30,500	39.19	1.048	.048	.002	0	
1910	25,080	30,400	41.89	1.043	.043	.002	0	
1911	16,800	29,100	44.59	1.000	0	0		0
1912	42,000	28,300	47.30	0.972	.028	.001		0
1913	46,000	27,000	50.00	.928	.072	.005		0
1914	15,500	27,000	52.70	.928	.072	.005		0
1915	23,400	25,500	55.41	.875	.125	.016		.002
1916	42,200	25,100	58.11	.862	.138	.019		.003
1917	25,000	25,000	60.81	.859	.141	.020		.003
1918	23,400	24,000	63.51	.825	.175	.031		.005
1919	47,000	23,500	66.22	.809	.191	.037		.007
1920	27,000	23,400	68.92	.804	.196	.030		.007
1921	32,000	23,400	71.62	.804	.196	.039		.007
1922	35,200	22,300	74.32	.766	.234	.055		.013
1923	25,500	19,900	77.03	.684	.316	.100		.030
1924	19,900	19,500	79.73	.670	.330	.109		.036
1925	68,500	16,800	82.43	.577	.423	.179		.076
1926	23,500	16,300	85.14	.560	.440	.194		.085
1927	12,200	15,500	87.84	.533	.467	.220		.101
1928	27,000	14,400	90.54	.495	.505	.255		.129
1929	49,600	12,400	93.24	.426	.574	.330		.189
1930	12,400	12,200	95.95	.419	.581	.339		.196
1931	9,600	9,600	98.65	.330	.670	.449		.300
Total	1,077,100			37.005		6.371	3.618	1.189
Mean	29,100							

$$\text{Coefficient of Variation} = \sqrt{\frac{6.371}{37 - 1}} = 0.420$$

$$\text{Coefficient of Skew (comp.)} = \frac{3.618 - 1.189}{(37 - 1)(0.420)^3} = 0.914$$

$$\text{Coefficient of Skew (adj.)} = 0.914 \times 1.230 = 1.12$$

Ocmulgee River at Macon, Georgia. Goodrich Straight Line method.
Tabulated data. 37 year record. January 1895 - December 1931.

R = discharge arranged in order of magnitude c.f.s.	Percent time for plotting	R in terms of mean.	R - 0.3
9,600	1.35	0.330	0.030
12,200	4.05	.419	.119
12,400	6.76	.426	.126
14,400	9.46	.495	.195
15,500	12.16	.533	.233
16,300	14.86	.560	.260
15,800	17.57	.577	.277
19,500	20.27	.670	.370
19,900	22.97	.684	.384
22,300	25.68	.766	.466
23,400	28.38	.804	.504
23,400	30.08	.804	.504
23,500	33.78	.809	.509
24,000	36.49	.825	.525
25,000	39.19	.859	.559
25,100	41.89	.862	.562
25,500	44.59	.875	.575
27,000	47.30	.928	.628
27,000	50.00	.928	.628
28,300	52.70	.972	.672
29,100	55.41	1.000	.700
30,400	58.11	1.043	.743
30,500	60.81	1.048	.748
31,600	63.51	1.085	.785
31,700	66.22	1.089	.789
31,800	68.92	1.092	.792
32,000	71.62	1.100	.800
35,200	74.32	1.210	.910
36,400	77.03	1.250	.950
39,000	79.73	1.340	1.040
42,000	82.43	1.442	1.142
42,200	85.14	1.450	1.150
43,000	87.84	1.475	1.175
46,000	90.54	1.580	1.280
47,000	93.24	1.615	1.315
49,600	95.95	1.705	1.405
68,500	98.65	2.355	2.055

Ocmulgee River at Macon, Georgia. Monthly Flood method.
37 year record. January 1895 - December 1931.
(Flows above 20,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting $= \frac{100(m - 0.5g)}{n}$
68,500		1	0.113
49,600		2	.338
49,000		3	.564
46,000		4	.789
45,000		5	1.01
44,200		6	1.24
43,000		7	1.47
42,200		8	1.69
42,000		9	1.92
39,000		10	2.14
36,400		11	2.25
35,200		12	2.59
32,200		13	2.82
32,000		14	3.04
31,800		15	3.27
31,700		16	3.49
31,200		17	3.72
30,500		18	3.95
30,400		19	4.17
29,600		20	4.40
29,500		21	4.61
29,100		22	4.85
28,300		23	5.07
27,600		24	5.30
27,000	2	26	5.63
26,000-24,000	6	32	6.54
24,000-22,000	7	39	8.00
22,000-20,000	6	45	9.46

$n = 12 \times 37 = 444$

Ocmulgee River at Macon, Georgia. Daily Flow method.
37 year record. January 1895 - December 1931.
(Flows above 20,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
68,500		1	0.00370
67,500		2	.0111
49,600		3	.0185
49,000		4	.0259
47,000		5	.0333
46,000		6	.0407
45,000	2	8	.0518
44,200		9	.0629
44,000	2	11	.0777
43,000	2	13	.0889
42,200		14	.1000
42,000		15	.1072
40,500	2	17	.1183
40,000		18	.1295
39,500		19	.1369
39,000		20	.1442
36,500		21	.1519
36,400		22	.1590
36,000		23	.1668
35,500		24	.1740
35,200		25	.1812
33,500		26	.1888
32,600		27	.196
32,200		28	.204
32,000		29	.211
31,800		30	.218
31,700		31	.226
31,500		32	.233
31,200		33	.240
30,000		34	.248
30,400		35	.255
30,000	3	38	.270
30,000-28,000	11	49	.322
28,000-26,000	11	60	.404
26,000-24,000	17	77	.507
24,000-22,000	30	107	.681
22,000-20,000	21	128	.871

n = 365 x 37 = 13,505

Ocmulgee River at Macon, Georgia. Flood Event and Modified California methods. 37 year record. January 1895 - December 1931.
(Flows above 20,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California Method. Average number of events per century = 159.5 x per cent of flood peaks.
68,500		1	0.846	1.35
49,600		2	2.540	4.04
49,000		3	4.24	6.75
46,000		4	5.93	9.44
45,000	2	6	8.46	13.50
44,200		7	11.02	17.55
43,000		8	12.70	20.20
42,200		9	14.40	22.90
42,000		10	16.10	25.60
39,000		11	17.80	28.30
36,400		12	19.48	30.95
35,200		13	21.20	33.70
32,200		14	22.90	36.40
32,000		15	24.55	39.00
31,800		16	26.25	41.70
31,700		17	27.95	44.40
31,500		18	29,65	47.10
31,200		19	31.35	49.90
30,500		20	33.05	52.60
30,400		21	34.75	55.20
29,500		22	36.40	57.9
29,100		23	38.15	60.6
27,600		24	39.80	63.3
27,500		25	41.50	66.0
27,400		26	43.20	68.7
27,000	2	28	45.70	72.8
26,000		29	48.30	76.9
25,500	2	31	50.90	80.9
25,100		32	53.4	84.9
25,000		33	55.0	87.5
24,800		34	56.8	90.4
24,600		35	58.5	93.0
24,400		36	60.1	95.5
24,200		37	61.9	98.5
24,000		38	63.5	101.2
23,800		39	65.1	104.0
23,700	2	41	67.8	108.0
23,500		42	70.4	112.0
23,400		43	72.0	114.8
23,300		44	73.7	117.5
22,800		45	75.4	120.0
22,500	2	47	78.0	124.2
22,400		48	80.5	128.2
22,300		49	82.0	131.0
22,000		50	83.9	133.7
21,700		51	85.5	136.1
21,500		52	87.2	139.0
21,400		53	89.0	141.8
21,100		54	90.6	144.5
21,000		55	92.4	147.0
20,500		56	94.0	150.0
20,200	2	58	96.6	154.0
20,000		59	99.2	158.0

n = 59 flood peaks. Events per century = (59)100 = 159.5

Ocmulgee River at Macon, Georgia. The Fuller Formula.

$$Q = C A^{0.8}(1 + 0.8 \log T)$$

Drainage area $=$ 2,283 square miles.

$A^{0.8} = 484$

Ave. $Q = 29{,}110$ c.f.s.

$C = \frac{29{,}110}{484} = 60$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	60	484	1.60	2.60	75,500
50			1.36	2.36	68,500
10			0.80	1.80	52,200
5			0.56	1.56	45,200

Ocmulgee River at Macon, Georgia. The Pettis Formula.

$$Q = 328\ P\ W^{5/4}$$

Drainage area $=$ 2,283 square miles.

Length of river $=$ 99 miles (scaled from map).

Then $W = \frac{2{,}283}{99} = 23.10$

and $W^{5/4} = 50.4$

From Plate 6, following page 51, P is found to be 13.2 inches.

Then $Q = 328 \times 13.2 \times 50.4 = 182{,}000$ c.f.s.

5. <u>Oconee River at Fraley's Ferry, Georgia.</u>

Oconee River at Fraley's Ferry, Georgia. Annual Flood computations. 28 year record. January 1904 - December 1931.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1904	10,820	75,000	1.79	2.050	1.050	1.100	1.160	
1905	20,500	73,600	5.36	2.010	1.010	1.020	1.030	
1906	32,000	71,000	8.93	1.945	0.945	0.890	0.840	
1907	19,800	65,200	12.50	1.790	.785	.615	.482	
1908	61,000	61,000	16.07	1.670	.670	.449	.300	
1909	36,000	54,500	19.64	1.495	.495	.245	.121	
1910	15,900	51,500	23.21	1.410	.410	.168	.068	
1911	25,700	45,700	26.79	1.252	.252	.064	.016	
1912	51,500	42,000	30.36	1.150	.150	.023	.004	
1913	71,000	41,550	33.93	1.140	.140	.020	.003	
1914	22,800	40,500	37.50	1.112	.112	.013	.001	
1915	24,900	36,000	41.07	0.988	.012	.004		0
1916	18,300	35,500	44.64	.975	.025	.006		0
1917	29,300	32,000	48.21	.878	.122	.015		.002
1918	26,500	29,300	51.79	.803	.197	.039		.008
1919	45,700	26,500	55.36	.726	.274	.075		.021
1920	40,500	25,700	58.93	.705	.295	.087		.026
1921	41,550	24,900	62.50	.682	.318	.101		.030
1922	54,500	23,900	66.07	.655	.345	.119		.041
1923	35,500	22,800	69.64	.625	.375	.140		.055
1924	42,000	20,600	73.21	.565	.435	.189		.082
1925	65,200	20,500	76.79	.562	.438	.192		.084
1926	23,900	20,000	80.36	.549	.451	.205		.092
1927	18,500	19,800	83.93	.544	.456	.209		.095
1928	73,600	18,500	87.50	.506	.494	.244		.120
1929	75,000	18,300	91.07	.501	.499	.249		.124
1930	20,000	15,900	94.64	.436	.564	.316		.178
1931	20,600	10,820	98.21	.297	.703	.494		.345
Total	1,022,570			28.021		7.291	4.025	1.303
Mean	36,520							

Coefficient of Variation $= \sqrt{\frac{7.291}{28 - 1}} = 0.520$

Coefficient of Skew (comp.) $= \frac{4.025 - 1.303}{(28 - 1)(0.520)^3} = 0.720$

Coefficient of Skew (adj.) $= 0.720 \times 1.303 = 0.940.$

When the computed curve for this coefficient of skew was plotted, it was that the points were not well represented. By trial a coefficient of skew (graphical) of 1.50 was found to best represent the record points.

Oconee River at Fraley's Ferry, Georgia. Goodrich Straight Line method. Tabulated data. 28 year record. January 1904 - December 1931.

R = discharge arranged in order of magnitude. c.f.s.	Per cent of time for plotting	R in terms of Mean	R - 0.25
10,820	1.79	0.297	0.047
15,900	5.36	.436	.186
18,300	8.93	.501	.251
18,500	12.50	.506	.256
19,800	16.07	.544	.294
20,000	19.64	.549	.299
20,500	23.21	.562	.312
20,600	26.79	.565	.315
22,800	30.36	.625	.375
23,900	33.93	.655	.405
24,900	37.50	.682	.432
25,700	41.07	.705	.455
26,500	44.64	.726	.476
29,300	48.21	.803	.553
32,000	51.79	.878	.628
35,500	55.36	.975	.725
36,000	58.93	.988	.738
40,500	62.50	1.112	.862
41,550	66.07	1.140	.890
42,000	69.64	1.150	.900
45,700	73.21	1.252	1.002
51,500	76.79	1.410	1.160
54,600	80.36	1.495	1.245
61,000	83.93	1.670	1.420
65,200	87.50	1.790	1.540
71,000	91.07	1.945	1.695
73,600	94.64	2.010	1.760
75,000	98.21	2.050	1.800

Oconee River at Fraley's Ferry, Georgia. Monthly Flood method.
29 year record. January 1904 - December 1931.
(Flows above 20,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
75,000		1	0.161
73,600		2	.480
71,000		3	.810
68,500		4	1.13
67,600		5	1.45
65,200		6	1.77
54,500		7	2.09
51,500		8	2.42
45,700		9	2.74
42,000		10	3.06
41,550		11	3.39
40,500		12	3.71
37,400	2	14	4.20
35,500		15	4.68
29,800	2	17	5.16
29,300		18	5.64
28,500		19	5.96
27,300		20	6.29
26,500		21	6.60
25,700		22	6.94
24,900		23	7.25
24,600	2	25	7.74
24,200		26	8.23
23,900	3	29	8.86
23,200	3	32	9.85
22,800	2	34	10.62
22,400		35	11.12
22,100		36	11.43
21,500		37	11.78
21,200		38	12.10
20,900		39	12.40
20,600	2	41	12.90
20,500		42	13.38
20,000		43	13.70

n = 310

Oconee River at Fraley's Ferry, Georgia. Daily Flow method.
26 year record. 1904-1931*.
(Flows above 20,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
75,000		1	0.00530
73,600		2	.01590
72,200		3	.0265
71,000		4	.0371
68,500		5	.0477
67,600		6	.0583
65,200		7	.0689
61,500		8	.0795
59,200		9	.090
57,800	2	11	.106
57,500		12	.122
55,500		13	.133
54,500		14	.143
51,500		15	.154
50,300		16	.164
49,400		17	.175
47,600	2	19	.191
46,600		20	.207
45,700	2	22	.223
44,800		23	.238
44,300		24	.249
43,800		25	.260
42,400		26	.270
42,000		27	.281
41,550		28	.292
41,100	2	30	.307
40,500		31	.323
40,200	2	33	.339
39,000		34	.355
38,800		35	.366
38,300	2	37	.382
37,900		38	.397
37,400	2	40	.414
37,300		41	.429
36,400	3	44	.450
35,500		45	.471
35,000-30,000	8	53	.520
30,000-25,000	25	78	.695
25,000-20,000	71	149	1.204

*Record consists in years 1904, 05, 07, 1910 - 1931, inclusive, plus 7 months of 1906 and 3 months of 1909.

n = 9437

Oconee River at Fraley's Ferry, Georgia. Flood Event and Modified California Methods. 28 year record. January 1904 - December 1931. (Flows above 24,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California method. Average number of events per century = 143 x per cent of flood peaks.
75,000		1	1.25	1.79
73,600		2	3.75	5.35
71,000		3	6.25	8.94
68,500		4	8.75	12.50
67,600		5	11.25	16.08
65,200		6	13.75	19.65
61,000		7	16.25	23,20
54,500		8	18.75	26.8
51,500		9	21.25	30.4
46,600		10	23.75	33.9
45,700		11	26.20	37.4
44,300		12	28.8	41.1
42,000		13	31.2	44.6
41,550		14	33.8	48.3
40,500		15	36.2	51.6
40,200		16	38.8	55.4
38,200		17	41.2	58.9
37,400	2	19	45.0	64.3
36,000		20	48.7	69.5
35,500		21	51.2	73.1
33,200		22	53.7	76.6
32,000		23	56.2	80.1
29,800	2	25	60.0	85.7
29,300		26	63.7	91.0
28,900		27	66.2	94.5
28,500		28	68.7	98.3
28,100	2	30	72.5	103.6
27,300		31	76.2	109.0
26,900		32	78.7	112.2
26,500	2	34	85.0	121.5
26,000		35	86.2	123.2
25,700		36	88.7	126.8
24,900		37	91.2	130.5
24,600	2	39	95.0	136.0
24,200		40	98.7	141.0

n = 40 flood peaks.

Average number of events per century = $\frac{(40)100}{28}$ = 143

Oconee River at Fraley's Ferry. The Fuller Formula.

$$Q = C\,A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 2,815 square miles.

$$A^{0.8} = 575$$

Ave. Q = 36,520 c.f.s.

$$C = \frac{36,520}{575} = 63.5$$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	63.5	575	1.60	2.60	95,000
50			1.36	2.36	86,000
10			0.80	1.80	66,000
5			0.56	1.56	57,000

Oconee River at Fraley's Ferry, Georgia. The Pettis Formula.

$$Q = 328\ P\ W^{5/4}$$

Drainage area = 2,815 square miles.

Length of river = 112 miles (scaled from map).

Then $W = \dfrac{2815}{115} = 25.1$

and $W^{5/4} = 56.1$

From Plate 6, following page 51, P is found to be 13 inches.

Then Q = 328 x 13 x 56.1 = 239,000 c.f.s.

6. Santee River at Ferguson, South Carolina.

Santee River at Ferguson, South Carolina. Annual Flood computations.
22 year record. January 1908 - December 1929.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting Position	In terms of Mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1908	344,000	368,000	2.27	2.795	1.795	3.220	5.790	
1909	101,000	344,000	6.82	2.610	1.610	2.600	4.180	
1910	50,000	260,000	11.36	1.972	0.972	0.945	0.920	
1911	80,000	248,000	15.91	1.882	.882	.778	.685	
1912	209,000	209,000	20.45	1.588	.588	.345	.204	
1913	98,000	149,000	25.00	1.132	.132	.017	.002	
1914	62,000	146,000	29.55	1.110	.110	.012	.001	
1915	71,000	143,000	34.09	1.088	.088	.006	.001	
1916	368,000	101,000	38.64	0.766	.234	.055		0.013
1917	74,000	101,000	43.18	.766	.234	.055		.013
1918	80,000	98,000	47.73	.744	.256	.066		.017
1919	146,000	92,000	52.27	.699	.301	.091		.027
1920	53,000	89,000	56.82	.669	.331	.110		.036
1921	149,000	80,000	61.36	.607	.393	.154		.061
1922	101,000	80,000	69.91	.607	.393	.154		.061
1923	89,000	74,000	70.45	.561	.439	.192		.084
1924	92,000	71,000	75.00	.529	.461	.213		.098
1925	143,000	62,000	79.55	.471	.529	.280		.147
1926	35,000	53,000	84.09	.403	.597	.356		.212
1927	44,000	50,000	88.64	.380	.620	.385		.239
1928	248,000	44,000	93.18	.334	.666	.445		.295
1929	260,000	35,000	97.73	.266	.734	.538		.392
Total	2,897,000			21.989		11.017	11.783	1.695
Mean	131,680							

$$\text{Coefficient of Variation} = \sqrt{\frac{11.017}{22 - 1}} = 0.724$$

$$\text{Coefficient of Skew (comp.)} = \frac{11.783 - 1.695}{(22 - 1)(0.724)^3} = 1.27$$

$$\text{Coefficient of Skew (adj.)} = 1.386 \times 1.27 = 1.76$$

When the computed curve for this coefficient of skew was plotted, it was found that the points were not well represented. By trial a coefficient of skew (graphical) of 2.00 was found to fit best the record points.

Santee River at Ferguson, South Carolina. Goodrich Straight Line method. Tabulated data. 22 year record. January 1908 - December 1929.

R = discharge arranged in order of magnitude c.f.s.	Per cent of time for plotting	R in terms of Mean	R - 0.25
35,000	2.27	0.266	0.016
44,000	6.82	.334	.084
50,000	11.36	.380	.130
53,000	15.91	.403	.153
62,000	20.45	.471	.221
71,000	25.00	.539	.289
74,000	29.55	.561	.311
80,000	34.09	.607	.357
80,000	38.64	.607	.357
89,000	43.18	.669	.419
92,000	47.73	.699	.449
98,000	52.27	.744	.494
101,000	56.82	.766	.516
101,000	61.36	.766	.516
143,000	65.91	1.088	.838
146,000	70.45	1.110	.860
149,000	75.00	1.132	.882
209,000	79.55	1.588	1.338
248,000	84.09	1.882	1.632
260,000	88.64	1.972	1.722
344,000	93.18	2.610	2.460
368,000	97.73	2.795	2.545

Santee River at Ferguson, South Carolina. Monthly Flood method.
22 year record. January 1908 - December 1929.
(Flows above 40,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
368,000		1	0.1892
344,000		2	.568
323,000		3	.948
260,000		4	1.325
248,000		5	1.705
209,000		6	2.085
155,000		7	2.46
149,000		8	2.84
146,000		9	3.22
143,000		10	3.60
125,000		11	3.97
104,000		12	4.35
101,000	2	14	4.92
98,000		15	5.49
92,000		16	5.86
89,000		17	6.25
83,000	2	19	6.81
80,000	2	21	7.58
77,000		22	8.14
74,000		23	8.50
71,000	2	25	9.09
68,000	2	27	9.85
65,000		28	10.42
62,000		29	10.80
59,000		30	11.18
56,000	2	32	11.73
53,000	6	38	13.25
50,000	10	48	16.30
47,000	6	54	19.30
44,000	13	67	22.90
41,000	11	78	27.45

n = 12 x 22 = 264.

Santee River at Ferguson, South Carolina. Daily Flow method.
22 year record. January 1908 - December 1929.
(Flows above 60,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
368,000		1	0.00622
365,000		2	.0187
344,000		3	.0311
323,000		4	.0435
311,000		5	.0560
278,000		6	.0684
266,000		7	.0809
263,000		8	.0935
260,000	2	10	.1120
248,000	2	12	.1368
233,000		13	.1555
221,000		14	.1680
215,000		15	.1803
209,000	3	18	.205
203,000		19	.230
197,000		20	.243
179,000	2	22	.261
167,000		23	.280
164,000		24	.292
161,000		25	.305
155,000	3	28	.330
149,000		29	.354
146,000		30	.367
143,000	4	34	.398
140,000		35	.429
137,000	5	40	.466
134,000		41	.504
131,000		42	.516
128,000		43	.527
125,000	4	47	.560
122,000	2	49	.596
119,000	2	51	.621
116,000		52	.640
113,000		53	.653
110,000	2	55	.671
104,000	2	57	.696
101,000	4	61	.734
98,000	3	64	.776
95,000	3	67	.815
92,000	5	72	.865
89,000	5	77	.927
86,000	4	81	.984
83,000	9	90	1.063
80,000	4	94	1.145
77,000	5	99	1.200
74,000	5	104	1.265
71,000	11	115	1.365
68,000	13	128	1.515
65,000	8	136	1.645
62,000	15	151	1.788

n = 22 x 365 = 8030

Santee River at Ferguson, South Carolina. Flood Event and Modified California methods. 22 year record. January 1908 - December 1929. (Flows above 40,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California method. Average number of events per century = 464 x per cent of flood peaks.
368,000		1	.490	2.27
344,000		2	1.470	6.81
260,000		3	2.450	11.33
248,000		4	3.430	15.90
209,000		5	4.410	20.45
155,000		6	5.390	24.95
149,000		7	6.37	29.55
146,000		8	7.35	34.05
143,000		9	8.34	36.6
137,000		10	9.30	43.1
125,000		11	10.30	47.7
122,000		12	11.28	52.3
104,000		13	12.26	56.8
101,000	2	15	13.72	63.5
98,000		16	15.19	70.4
92,000		17	16.18	75.0
89,000		18	17.15	79.5
83,000	2	20	18.61	86.3
80,000	2	22	20.60	95.3
77,000		23	22.05	102.2
74,000	2	25	23.5	109.0
71,000		26	25.0	116.0
68,000	3	29	26.95	125.0
65,000		30	28.9	134.0
62,000	2	32	30.4	140.8
59,000	2	34	32.3	150.0
56,000	3	37	34.8	161.5
53,000	9	46	40.6	188.5
50,000	14	60	51.9	204.5
47,000	12	72	64.6	300.0
44,000	12	84	76.4	354.0
41,000	18	102	91.0	422.0

n = 102 flood peaks.

Average number of events per century = $\frac{(102)100}{22} = 464$

Santee River at Ferguson, South Carolina. The Fuller Formula.

$$Q = C\,A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 14,800 square miles.

$A^{0.8} = 2185$

Ave. Q = 131,680 c.f.s.

$$C = \frac{131{,}680}{2185} = 60$$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	60	2185	1.60	2.60	341,000
50			1.36	2.36	310,000
10			0.80	1.80	236,000
5			0.56	1.56	205,000

Santee River at Ferguson, South Carolina. The Pettis Formula.

$$Q = 328\ P\ W^{5/4}$$

Drainage area = 14,800 square miles

Length of river = 286 miles (scaled from map).

$$W = \frac{14{,}800}{286} = 51.8$$

$$W^{5/4} = 139.0$$

From Plate 6, following page 51, P is found to be 12 inches.

Then $Q = 328 \times 139 \times 12 = 548{,}000$ c.f.s.

7. Savannah River at Augusta, Georgia.

Savannah River at Augusta, Georgia. Annual Flood computations.
57 year record. January 1876 - December 1932*.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting position	In terms of Mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1876	71,600	350,000	0.88	2.845	1.850	3.430	6.280	
1877	106,000	300,000	2.63	2.440	1.440	2.070	3.000	
1878	60,000	300,000	4.39	2.440	1.440	2.070	3.000	
1879	110,000	226,000	6.14	1.840	0.840	0.705	0.590	
1880	93,000	203,000	7.90	1.652	.650	.422	.275	
1881	133,000	200,000	9.65	1.630	.630	.396	.250	
1882	80,000	177,000	11.40	1.440	.440	.194	.086	
1883	107,000	176,000	13.15	1.435	.435	.190	.082	
1884	88,500	176,000	14.90	1.435	.435	.190	.082	
1885	84,500	170,000	16.65	1.385	.385	.148	.057	
1886	138,000	167,000	18.45	1.360	.360	.130	.047	
1887	176,000	161,000	20.20	1.315	.315	.099	.031	
1888	300,000	156,000	21.95	1.270	.270	.073	.020	
1889	146,000	150,000	23.70	1.220	.220	.048	.011	
1890	94,000	146,000	25.45	1.190	.190	.036	.007	
1891	200,000	144,000	27.20	1.170	.170	.029	.005	
1892	144,000	138,000	29.00	1.125	.125	.016	.002	
1893	68,000	133,000	30.70	1.080	.080	.006	.001	
1894	86,000	131,000	32.45	1.070	.070	.005	.0	
1895	111,000	126,000	34.20	1.028	.028	.001	0	
1896	111,000	125,000	36.000	1.020	.020	0	0	
1897	94,000	120,000	37.75	0.979	.021	0		0
1898	92,500	118,000	39.50	.961	.039	.002		0
1899	118,000	118,000	41.40	.961	.039	.002		0
1900	131,000	111,000	43,00	.905	.095	.009		.001
1901	126,000	111,000	44.80	.905	.095	.009		.001
1902	176,000	110,000	46.50	.896	.104	.011		.001
1903	150,000	110,000	48.40	.896	.104	.011		.001
1904	70,500	107,000	50.00	.873	.127	.016		.002
1905	91,500	106,000	51.80	.864	.136	.018		.003
1906	104,500	104,500	53.50	.854	.146	.021		.003
1907	91,500	100,000	55.3	.815	.185	.034		.006
1908	300,000	96,000	57.0	.784	.216	.047		.010
1909	91,000	94,000	58.8	.766	.234	.055		.013
1910	77,000	94,000	60.5	.766	.234	.055		.013
1911	125,000	93,000	62.3	.759	.241	.058		.014
1912	203,000	92,500	64.0	.755	.245	.060		.015
1913	177,000	91,500	65.9	.745	.255	.065		.017
1914	70,000	91,500	67.5	.745	.255	.065		.017
1915	96,000	91,000	69.4	.741	.259	.067		.017
1916	120,000	90,000	71.0	.735	.265	.070		.019
1917	100,000	88,500	72.9	.721	.279	.078		.022
1918	156,000	86,000	74.5	.701	.299	.089		.027
1919	167,000	84,500	76.4	.689	.311	.097		.030
1920	110,000	80,000	78.0	.652	.348	.121		.042

Continued on next page

Savannah River at Augusta, Georgia. Annual Flood computations (contd.).

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	-
1921	161,000	78,000	79.9	0.635	0.365	0.133		0.048
1922	118,000	77,000	81.5	.629	.371	.138		.051
1923	69,000	71,000	83.4	.579	.421	.178		.074
1924	78,000	70,500	85.0	.575	.425	.180		.076
1925	170,000	70,000	86.9	.570	.430	.185		.079
1926	64,000	69,000	88.6	.563	.437	.192		.084
1927	46,000	68,000	90.4	.555	.445	.198		.088
1928	226,000	64,000	92.0	.522	.478	.229		.109
1929	350,000	60,000	93.9	.490	.510	.260		.133
1930	34,000	46,900	95.6	.382	.618	.382		.236
1931	46,900	46,000	97.4	.375	.625	.390		.244
1932	90,000	34,000	99.1	.277	.723	.522		.378
Total	6,997,400			57.021		14.275	13.826	1.874
Mean	122,760							

Coefficient of Variation $= \sqrt{\dfrac{14.275}{57 - 1}} = 0.512$

Coefficient of skew (comp.) $= \dfrac{13.826 - 1.874}{(57 - 1)(0.512)^3} = 1.580$

Coefficient of skew (adj.) $= 1.580 \times 1.49 = 1.812$

*At this station, all values of discharge are peak or instantaneous values, and not average daily discharges.

The record at this station was not available in form to permit analysis by the Daily Flow and Monthly Flow methods, hence, these two methods of analysis are omitted.

Savannah River at Augusta, Georgia. Goodrich Straight Line method. Tabulated data. 57 year record. January 1876 - December 1932.

R = discharge arranged in order of magnitude c.f.s.	Per cent of time for plotting	R in terms of Mean	R - 0.25
34,000	0.88	0.28	0.03
46,000	2.63	.38	.13
46,900	4.39	.38	.13
60,000	6.14	.49	.24
64,000	7.90	.52	.27
68,000	9.65	.56	.31
69,000	11.40	.56	.31

Continued on next page

Savannah River at Augusta, Georgia. Goodrich Straight Line Method (Continued).

R = discharge arranged in order of magnitude c.f.s.	Per cent of time for plotting	R in terms of mean	R - 0.25
70,000	13.15	0.57	0.32
70,500	14.90	.58	.33
71,000	16.65	.58	.33
77,000	18.45	.63	.38
78,000	20.20	.64	.39
80,000	21.95	.65	.40
84,500	23.70	.69	.44
86,000	25.45	.70	.45
88,500	27.20	.72	.47
90,000	29.00	.74	.49
91,000	30.70	.74	.49
91,500	32.45	.75	.50
91,500	34.20	.75	.50
92,500	36.00	.76	.51
93,000	37.75	.76	.51
94,000	39.50	.77	.52
94,000	41.40	.77	.52
96,000	43.0	.78	.53
100,000	44.8	.82	.57
104,500	46.5	.85	.60
106,000	48.7	.86	.61
107,000	50.0	.87	.62
110,000	51.8	.90	.65
110,000	53.5	.96	.65
111,000	55.3	.91	.66
118,000	58.8	.96	.71
118,000	60.5	.96	.71
120,000	62.3	.98	.73
125,000	64.0	1.02	.77
126,000	65.9	1.03	.78
131,000	67.5	1.07	.82
133,000	69.4	1.08	.83
138,000	71.0	1.13	.88
144,000	72.9	1.17	.92
146,000	74.5	1.19	.94
150,000	76.4	1.22	.97
156,000	78.0	1.27	1.02
161,000	79.9	1.32	1.07
167,000	81.5	1.36	1.11
170,000	83.4	1.39	1.14
176,000	85.0	1.43	1.18
176,000	86.9	1.44	1.19
177,000	88.6	1.44	1.19
200,000	90.4	1.63	1.38
203,000	92.0	1.65	1.40
226,000	93.9	1.84	1.59
300,000	95.6	2.44	2.19
300,000	97.4	2.44	2.19
350,000	99.1	2.85	2.60

Savannah River at Augusta, Georgia. Flood Event and Modified California methods. 57 year record. January 1876 - December 1932.
(Flows above 68,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California method. Average number of events per century = 222.5 x per cent of flood peaks.
350,000		1	0.394	0.875
300,000	2	3	1.58	3.51
226,000		4	2.76	6.15
200,000		5	3.54	7.87
194,000		6	4.34	9.65
193,000		7	5.11	11.38
177,000		8	5.91	13.15
176,000		9	6.70	14.90
175,000		10	7.48	16.67
170,000		11	8.26	18.40
167,000		12	9.07	20.2
161,000		13	9.85	21.9
156,000		14	10.65	23.7
150,000		15	11.42	25.4
148,000		16	12.20	27.2
146,000		17	13.00	28.9
144,000		18	13.80	29.1
140,000	2	20	14.96	33.2
138,000		21	16.18	35.9
133,000	2	23	17.35	38.6
131,000		24	18.50	41.1
126,000	2	26	19.70	43.9
125,000		27	20.90	46.5
120,000	2	29	22.10	49.1
118,000	2	31	23.60	52.5
115,000		32	24.80	55.1
113,000		33	25.60	57.0
111,000	2	35	26.80	59.5
110,000	3	38	28.75	63.9
107,000	3	41	31.10	69.1
106,000	3	44	33.50	74.5
105,000	2	46	35.40	78.6
104,500	2	48	37.00	82.3
100,000	3	51	39.00	86.7
100,000-95,000	6	57	42.50	94.5
95,000-90,000	14	71	50.4	112.0
90,000-85,000	15	86	61.9	137.5
85,000-80,000	11	97	72.0	160.0
80,000-75,000	9	106	80.0	178.0
75,000-68,000	21	127	92.0	204.0

n = 127 flood peaks

Average number of events per century = $\frac{(127)100}{57}$ = 222.5

Savannah River at Augusta, Georgia. The Fuller Formula.

$$Q = C\,A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 7245 square miles.

$$A^{0.8} = 707$$

$$\text{Ave. } Q = 122{,}760 \text{ c.f.s.}$$

$$C = \frac{122{,}760}{707} = 173.5$$

Interval in Years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	173.5	707	1.60	2.60	320,000
50			1.36	2.36	290,000
10			0.80	1.80	221,000
5			0.56	1.56	192,000

Savannah River at Augusta, Georgia. The Pettis Formula.

$$Q = 328\, P\, W^{5/4}$$

Drainage area = 7245 square miles.

Length of river = 190 miles (scaled from map).

$$W = \frac{7245}{190} = 38.2$$

$$W^{5/4} = 95.0$$

From Plate 6, following page 51, P is found to be 13 inches.

Then $Q = 328 \times 13 \times 95.0 = 405{,}000$ c.f.s.

8. Tennessee River at Chattanooga, Tennessee.

Tennessee River at Chattanooga, Tennessee. Annual Flood computations.
58 year record. October 1874 - September 1932.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1874-75	361,000	361,000	0.86	1.749	0.749	0.560	0.420	
1875-76	227,000	349,000	2.58	1.690	.690	.475	.328	
1876-77	189,000	310,000	4.31	1.502	.502	.252	.126	
1877-78	125,000	285,000	6.04	1.380	.380	.144	.055	
1878-79	252,000	283,000	7.75	1.380	.380	.144	.055	
1879-80	254,000	275,000	9.49	1.333	.333	.111	.037	
1880-81	174,000	271,000	11.21	1.313	.313	.098	.031	
1881-82	267,000	269,000	12.93	1.303	.303	.092	.028	
1882-83	254,000	267,000	14.67	1.293	.293	.086	.025	
1883-84	285,000	266,000	16.39	1.289	.289	.084	.024	
1884-85	174,000	266,000	18.11	1.289	.289	.084	.024	
1885-86	349,000	259,000	19.82	1.255	.255	.065	.017	
1886-87	180,000	254,000	21.55	1.230	.230	.053	.012	
1887-88	178,000	254,000	33.30	1.230	.230	.053	.012	
1888-89	195,000	252,000	25.00	1.220	.220	.048	.011	
1889-90	283,000	252,000	26.70	1.220	.220	.048	.011	
1890-91	259,000	252,000	28.45	1.220	.220	.048	.011	
1891-92	252,000	248,000	30.20	1.201	.201	.040	.008	
1892-93	221,000	246,000	31.90	1.192	.192	.037	.007	
1893-94	167,000	229,000	33.60	1.110	.110	.012	.001	
1894-95	212,000	227,000	35.40	1.100	.100	.010	.001	
1895-96	269,000	221,000	37.05	1.070	.070	.005	0	
1896-97	252,000	220,000	38.80	1.066	.066	.004	0	
1897-98	164,000	217,000	40.50	1.051	.051	.003	0	
1898-99	266,000	212,000	42.25	1.028	.028	.001	0	
1899-00	157,000	210,000	44.00	1.018	.018	.0	0	
1900-01	217,000	210,000	46.50	1.018	.018	0	0	
1901-02	271,000	202,000	47.45	0.979	.021	0		0
1902-03	210,000	195,000	49.10	.945	.055	.003		0
1903-04	142,000	195,000	50.90	.945	.055	.003		0
1904-05	146,000	190,000	52.55	.921	.071	.005		0
1905-06	140,000	189,000	54.40	.916	.084	.007		.001
1906-07	220,000	189,000	56.00	.916	.084	.007		.001
1907-08	162,000	188,000	57.70	.911	.089	.008		.001
1908-09	163,000	183,000	59.50	.886	.114	.013		.001
1909-10	85,900	183,000	61.10	.886	.114	.013		.001
1910-11	195,000	183,000	63.00	.886	.114	.013		.001
1911-12	190,000	181,000	64.60	.877	.123	.015		.002
1912-13	202,000	180,000	66.40	.872	.128	.016		.002
1913-14	102,000	178,000	68.10	.863	.137	.019		.003
1914-15	183,000	174,000	69.90	.844	.156	.024		.004
1915-16	183,000	174,000	71.50	.844	.156	.024		.004
1916-17	310,000	167,000	73.30	.810	.190	.036		.007
1917-18	266,000	167,000	75.00	.810	.190	.036		.007
1918-19	189,000	164,000	76.70	.795	.205	.042		.009
1919-20	275,000	163,000	78.40	.789	.211	.045		.009
1920-21	210,000	162,000	80.10	.785	.215	.046		.010
1921-22	229,000	157,000	81.90	.761	.239	.057		.014
1922-23	180,000	146,000	83.50	.708	.292	.085		.025
1923-24	143,000	143,000	85.30	.693	.307	.094		.029
1924-25	138,000	142,000	87.00	.689	.311	.097		.030

Tennessee River at Chattanooga, Tennessee. Annual Flood computations. (Continued.)

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1925-26	92,900	140,000	88.70	0.679	0.321	0.103		0.033
1926-27	248,000	138,000	90.50	.669	.331	.110		.036
1927-28	181,000	125,000	92.20	.606	.394	.155		.061
1928-29	246,000	120,000	93.90	.581	.419	.175		.073
1929-30	167,000	102,000	95.60	.494	.506	.256		.130
1930-31	120,000	92,900	97.40	.450	.550	.302		.156
1931-32	183,000	85,900	99.05	.416	.584	.340		.199
Total	11,963,800			57.976		4.706	1.244	0.849
Mean	206,270							

$$\text{Coefficient of Variation} = \sqrt{\frac{4.706}{58 - 1}} = 0.288$$

$$\text{Coefficient of Skew (comp.)} = \frac{1.244 - 0.849}{(58 - 1)(0.288)^3} = 0.292$$

$$\text{Coefficient of Skew (adj.)} = 0.292 \times 1.147 = 0.334$$

Tennessee River at Chattanooga, Tennessee. Goodrich Straight Line method. Tabulated data. 58 year record. October 1874 - September 1932.

R = discharge arranged in order of magnitude c.f.s.	Per cent of time for plotting.	R in terms of mean.	R - 0.20
85,900	0.86	0.42	0.22
92,900	2.58	.45	.25
102,000	4.31	.49	.29
120,000	6.04	.58	.38
125,000	7.75	.61	.41
138,000	9.49	.67	.47
140,000	11.21	.68	.48
142,000	12.93	.69	.49
143,000	14.67	.69	.49
146,000	16.39	.71	.51
157,000	18.11	.76	.56
162,000	19.82	.79	.59
163,000	21.55	.79	.59
164,000	23.30	.80	.60
167,000	25.00	.81	.61

Continued on next page

Tennessee River at Chattanooga, Tennessee. Goodrich Straight Line method (continued).

R = discharge arranged in order of magnitude c.f.s.	Per cent of time for plotting	R in terms of mean	R - 0.20
167,000	26.70	0.81	0.61
174,000	28.45	.84	.64
174,000	30.20	.84	.64
178,000	31.90	.86	.66
180,000	33.60	.87	.67
181,000	35.40	.88	.68
183,000	37.05	.89	.69
183,000	38.80	.89	.69
183,000	40.50	.89	.69
188,000	42.25	.91	.71
189,000	44.00	.92	.72
189,000	45.60	.92	.72
190,000	47.45	.92	.72
195,000	49.10	.95	.75
195,000	50.90	.95	.75
202,000	52.55	.98	.78
210,000	54.40	1.02	.82
210,000	56.00	1.02	.82
212,000	57.70	1.03	.83
217,000	59.50	1.05	.85
220,000	61.10	1.07	.87
221,000	63.00	1.07	.87
227,000	64.60	1.10	.90
229,000	66.40	1.11	.91
246,000	68.10	1.19	.99
248,000	69.90	1.20	1.00
252,000	71.50	1.22	1.02
252,000	73.30	1.22	1.02
252,000	75.00	1.22	1.02
254,000	76.70	1.23	1.03
254,000	78.40	1.23	1.03
259,000	80.10	1.26	1.06
266,000	81.90	1.29	1.09
266,000	83.50	1.29	1.09
267,000	85.30	1.29	1.09
269,000	87.00	1.30	1.10
271,000	88.70	1.31	1.11
275,000	90.50	1.33	1.13
283,000	92.20	1.38	1.18
285,000	93.90	1.38	1.18
310,000	95.60	1.50	1.30
349,000	97.40	1.69	1.49
361,000	99.05	1.75	1.55

Tennessee River at Chattanooga, Tennessee. Monthly Flood method.
58 year record. October 1874 - September 1932.
(Flows above 150,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
361,000		1	0.072
357,000		2	.216
349,000		3	.359
310,000		4	.502
285,000		5	.646
283,000		6	.790
275,000		7	.934
271,000		8	1.08
269,000	2	10	1.29
267,000		11	1.51
266,000	2	13	1.73
259,000		14	1.94
254,000	3	17	2.23
252,000	4	21	2.74
249,000		22	3.10
248,000	2	24	3.31
246,000		25	3.52
244,000		26	3.67
232,000		27	3.82
231,000		28	3.96
229,000		29	4.10
227,000	2	31	4.31
221,000		32	4.53
220,000		33	4.67
217,000		34	4.82
215,000	3	37	5.25
212,000		38	5.40
210,000	2	40	5.61
205,000	2	42	5.90
204,000		43	6.11
202,000		44	6.25
201,000	2	46	6.47
200,000-195,000	4	50	6.90
195,000-190,000	3	53	7.40
190,000-185,000	4	57	7.91
185,000-180,000	7	64	8.70
180,000-175,000	3	67	9.56
175,000-170,000	4	71	9.90
170,000-165,000	7	78	10.70
165,000-160,000	11	89	11.99
160,000-155,000	3	92	13.00
155,000-150,000	6	98	13.64

n = 12 x 58 = 696

Tennessee River at Chattanooga, Tennessee. Daily Flow method.

58 year record. October 1874 - September 1932. (Flows above 150,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
361,000		1	0.0024
357,000		2	.007
349,000		3	.012
341,000	2	5	.019
336,000		6	.026
331,000		7	.031
314,000		8	.035
310,000		9	.040
309,000		10	.045
307,000		11	.050
304,000		12	.054
299,000		13	.059
286,000		14	.064
285,000		15	.069
283,000		16	.073
282,000		17	.078
280,000		18	.083
278,000		19	.087
276,000		20	.092
275,000		21	.097
273,000		22	.102
272,000		23	.106
271,000		24	.111
269,000	2	26	.118
267,000	6	32	.137
266,000	5	37	.163
264,000		38	.177
263,000		39	.182
261,000	3	42	.196
259,000		43	.201
258,000	3	46	.210
257,000		47	.220
254,000	4	51	.232
252,000	6	57	.255
250,000	7	64	.286
250,000-245,000	15	79	.338
245,000-240,000	8	87	.392
240,000-235,000	11	98	.437
235,000-230,000	8	106	.482
230,000-225,000	15	121	.536
225,000-220,000	12	135	.600
220,000-215,000	13	146	.660
215,000-210,000	11	157	.716
210,000-205,000	11	168	.769
205,000-200,000	19	187	.840
200,000-195,000	19	206	.930
195,000-190,000	24	230	1.030
190,000-185,000	21	251	1.138
185,000-180,000	33	284	1.265
180,000-175,000	36	320	1.429
175,000-170,000	20	340	1.560
170,000-165,000	30	370	1.680
165,000-160,000	39	409	1.840
160,000-155,000	30	439	2.005
155,000-150,000	46	485	2.185

n = 58 × 365 = 21,170.

Tennessee River at Chattanooga, Tennessee. Flood Event and Modified California methods. 58 year record. October 1874 - September 1932.

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California method. Average number of events per century = 177.5 x per cent of flood peaks.
361,000		1	0.485	0.86
349,000		2	1.46	2.59
310,000		3	2.43	4.31
285,000		4	3.40	6.04
283,000		5	4.36	7.75
275,000		6	5.34	9.49
271,000		7	6.30	11.19
269,000		8	7.27	12.91
267,000		9	8.25	14.66
266,000	2	11	9.71	17.28
259,000		12	11.16	19.80
254,000	3	15	13.10	23.25
252,000	4	19	16.50	29.3
249,000		20	18.92	33.6
248,000		21	19.90	35.3
246,000		22	20.85	37.0
244,000		23	21.82	38.8
231,000		24	22.8	40.5
229,000		25	23.8	42.2
227,000	2	27	25.2	44.7
225,000		28	26.7	47.4
221,000		29	27.6	49.1
220,000	2	31	29.1	51.6
217,000		32	30.6	54.4
215,000	3	35	32.5	57.7
212,000		36	34.5	61.2
210,000	2	38	35.9	63.7
205,000	2	40	38.8	68.9
202,000		41	39.3	69.8
201,000	2	43	40.7	72.4
200,000		44	42.2	75.0
200,000-195,000	4	48	44.6	79.1
195,000-190,000	6	54	49.5	87.9
190,000-185,000	5	59	54.9	97.5
185,000-180,000	8	67	61.1	108.5
180,000-175,000	5	72	67.5	119.8
175,000-170,000	5	77	72.4	128.4
170,000-165,000	6	83	77.6	138.0
165,000-160,000	11	94	86.0	152.5
160,000-155,000	3	97	92.6	164.5
155,000-150,000	6	103	97.0	172.0

n = 103 flood peaks.

Average number of events per century = $\frac{(103) \times 100}{58}$ = 177.5

Tennessee River at Chattanooga, Tennessee. The Fuller Formula.

$$Q = C\ A^{0.8}(1 + 0.8 \log T)$$

Drainage area = 21,400 square miles.

$A^{0.8} = 2920$

Ave. Q = 206,270 c.f.s.

$$C = \frac{206,270}{2920} = 70.5$$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + log T	Q c.f.s.
100	70.5	2920	1.60	2.60	535,000
50			1.36	2.36	485,000
10			0.80	1.80	370,000
5			0.56	1.56	321,000

Tennessee River at Chattanooga, Tennessee. The Pettis Formula.

$$Q = 328\ P\ W^{5/4}$$

Drainage area = 21,400 square miles.

Length of river = 390 miles (scaled from map)

$$W = \frac{21,400}{390} = 54.9$$

$$W^{5/4} = 148.0$$

From Plate 6, following page 51, P is found to be 10.5 inches.

Then Q = 328 x 10.5 x 148.0 = 510,000 c.f.s.

9. Yadkin River near Salisbury, North Carolina.

Yadkin River near Salisbury, North Carolina. Annual Flood computations. 19 year record. January 1907 - December 1909 and January 1912 - December 1927.

Year	Maximum Daily Disch. c.f.s.	Disch. in order of size	Plotting position	In terms of mean	Difference from 1	Difference squared	Cube of Difference +	Cube of Difference -
1907	38,000	107,000	2.63	1.979	0.979	0.959	0.937	
1908	67,888	103,000	7.89	1.904	.904	.817	.735	
1909	54,400	77,200	13.16	1.428	.428	.184	.079	
1912	103,000	72,200	18.42	1.335	.335	.112	.038	
1913	77,200	67,800	23.68	1.252	.252	.063	.016	
1914	50,200	66,000	28.95	1.220	.220	.048	.011	
1915	54,400	62,400	34.21	1.152	.152	.023	.004	
1916	107,000	54,400	39.47	1.005	.005	.000	.000	
1917	43,400	54,400	44.74	1.005	.005	.000	.000	
1918	42,000	50,200	50.00	0.929	.071	.005		0.001
1919	72,200	43,400	55.26	.803	.197	.039		.008
1920	37,400	42,800	60.53	.791	.209	.044		.009
1921	42,800	42,000	65.79	.776	.224	.050		.011
1922	25,000	38,000	71.05	.702	.298	.089		.027
1923	66,000	37,400	76.32	.691	.309	.096		.030
1924	62,400	33,600	81.58	.621	.379	.144		.054
1925	24,400	26,400	86.84	.488	.512	.263		.135
1926	33,600	25,000	92.11	.461	.539	.290		.156
1927	26,400	24,400	97.37	.451	.549	.301		.165
Total	1,027,600			18.993		3.627	1.820	0.596
Mean	54,084							

$$\text{Coefficient of Variation} = \sqrt{\frac{3.627}{19 - 1}} = 0.449$$

$$\text{Coefficient of Skew (comp)} = \frac{1.820 - 0.596}{(19 - 1)(0.449)^3} = 0.755$$

$$\text{Coefficient of Skew (adj.)} = 0.755 \times 1.447 = 1.09$$

Yadkin River near Salisbury, North Carolina. Goodrich Straight Line Method. Tabulated data. 19 year record. January 1907 - December 1909 and January 1912 - December 1927.

R = discharge arranged in order of magnitude, c.f.s.	Per cent for plotting.	R in terms of mean.	R - 0.4
24,400	2.63	0.45	0.05
25,000	7.89	.46	.06
26,400	13.16	.49	.09
33,600	18.42	.62	.22
37,400	23.68	.69	.29
38,000	28.95	.70	.30
42,000	34.21	.78	.38
42,800	39.47	.79	.39
43,400	44.74	.80	.40
50,200	50.00	.93	.53
54,400	55.26	1.01	.61
54,400	60.53	1.01	.61
62,400	65,79	1.15	.75
66,000	71.05	1.22	.82
67,000	76.32	1.25	.85
72,200	81.58	1.34	.94
77,200	86.84	1.43	1.03
103,000	92.11	1.90	1.50
107,000	97.37	1.98	1.58

Yadkin River near Salisbury, North Carolina. Monthly Flood method. 19 year record. January 1907 - December 1909, and January 1912 - December 1927. (Flows above 25,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting = $\frac{100(m - 0.5g)}{n}$
107,000		1	0.220
103,000		2	.660
77,200		3	1.10
72,200		4	1.57
71,700		5	1.98
67,800		6	2.41
66,000		7	2.85
57,200		8	3.29
54,400		9	3.73
54,200		10	4.16
54,000		11	4.61
50,200		12	5.05
48,200		13	5.49
45,200		14	5.83
44,700		15	6.36
43,400		16	6.80
42,800		17	7.24
42,200		18	7.69
38,600		19	8.13
38,000		20	8.56
37,400		21	9.00
36,200		22	9.45
35,700		23	9.86
34,400	2	25	10.52
33,600		26	11.20
33,400		27	11.62
32,800	2	29	12.30
32,000		30	12.95
31,800		31	13.40
30,800		32	13.82
30,000-29,000	1	33	14.25
29,000-28,000	3	36	15.15
28,000-27,000	1	37	16.00
27,000-26,000	3	40	16.90
26,000-25,000	3	43	18.20

$n = 12 \times 19 = 228.$

Yadkin River near Salisbury, North Carolina. Daily Flow method. 19 year record. January 1907 - December 1909 and January 1912 - December 1927. (Flows above 25,000 c.f.s.)

Flood Limits	g	m	Per cent for plotting $= \frac{100(m - 0.5g)}{n}$
107,000		1	0.007
103,000	2	3	.029
77,200		4	.051
72,000		5	.065
69,200	2	7	.087
67,800		8	.109
66,000		9	.123
63,600		10	.137
62,800		11	.152
62,400		12	.166
60,700		13	.181
57,200		14	.195
54,400	2	16	.271
54,200		17	.238
50,200		18	.253
48,200		19	.267
48,000		20	.282
46,800	2	22	.304
45,200		23	.325
44,700		24	.340
44,600		25	.354
43,400		26	.368
42,800		27	.383
42,200		28	.397
41,300		29	.411
39,300		30	.426
39,200		31	.441
38,600	2	33	.462
38,000		34	.484
37,400	2	36	.506
36,200		37	.527
35,700		38	.541
35,300	2	40	.564
35,000		41	.585
35,000-34,000	3	44	.614
34,000-33,000	8	52	.694
33,000-32,000	4	56	.780
32,000-31,000	3	59	.831
31,000-30,000	1	60	.860
30,000-29,000	5	65	.904
29,000-28,000	4	69	.969
28,000-27,000	5	74	1.032
27,000-26,000	6	80	1.112
26,000-25,000	10	90	1.229

$n = 365 \times 19 = 6935$

Yadkin River near Salisbury, North Carolina. Flood Event and Modified California Methods. 19 year record. January 1907 - December, 1909, and January 1912 - December 1927.
(Flows above 25,000 c.f.s.)

Flood Limits	g	m	Per cent of flood peaks = $\frac{100(m - 0.5g)}{n}$	Modified California method. Average number of events per century = 279 x per cent of flood peaks.
107,000		1	0.944	2.63
103,000		2	2.73	7.61
77,200		3	4.71	13.18
72,200		4	6.60	18.41
71,700		5	8.50	23.70
67,800		6	10.38	29.00
66,000		7	12.27	34.20
57,200		8	14.16	39.5
54,400	2	10	16.99	47.4
54,200		11	19.80	55.1
50,200		12	21.70	60.5
48,200		13	23.6	65.9
45,200		14	25.5	71.1
44,700		15	26.4	73.5
43,400		16	29.3	81.6
42,800		17	31.1	86.9
42,200		18	33.0	92.0
36,600		19	34.9	97.4
38,000		20	36.8	102.8
37,400		21	38.7	108.0
36,200		22	40.5	113.0
35,700		23	42.5	118.7
34,400	2	25	44.4	124.0
33,800		26	48.1	134.2
33,600		27	50.0	139.5
33,400	2	29	52.9	147.5
32,800	2	31	56.6	158.0
32,000		32	59.5	166.0
31,600	2	34	62.3	174.0
30,800		35	65.0	181.3
30,000-29,000	2	37	67.9	189.2
29,000-28,000	4	41	73.5	205.0
28,000-27,000	2	43	79.2	221.0
27,000-26,000	6	49	86.9	242.0
26,000-25,000	4	53	96.1	268.0

n = 53 flood peaks.

Average number of events per century = $\frac{(53)100}{19}$ = 279

Yadkin River near Salisbury, North Carolina. The Fuller Formula.

$$Q = C\ A^{0.8}(1 + 0.8 \log T)$$

Drainage area $=$ 3400 square miles.

$A^{0.8} = 660$

Ave. $Q =$ 57,084 c.f.s.

$$C = \frac{57{,}084}{660} = 82$$

Interval in years, T	C	$A^{0.8}$	0.8 log T	1 + 0.8 log T	Q c.f.s.
100	82	660	1.60	2.60	141,000
50			1.36	2.36	128,000
10			0.80	1.80	97,500
5			0.56	1.56	84,500

Yadkin River near Salisbury, North Carolina. The Pettis Formula.

$$Q = 328\ P\ W^{5/4}$$

Drainage area $=$ 3400 square miles.

Length of river $=$ 135 miles (measured from map).

$W = 25.2$

$W^{5/4} = 56.2$

From Plate 6, following page 51, P is found to be 11.0 inches.

Then $Q = 328 \times 11.0 \times 56.2 = 202{,}500$ c.f.s.

APPENDIX IV

SOURCES OF FLOW DATA

Sources of all data used in this study are given below:

1. Chattahoochee River at West Point, Georgia. Oct. 1896 - Sept. 1910, and Oct. 1911 - September 1932. Water Supply Papers (U. S. Geological Survey) Nos. 197, 204, 242, 262, 282, 322, 352, 382, 402, 432, 452, 472, 502, 522, 542, 562, 582, 602, 622, 642, 662, 682, 697, 712, 727.

2. Cumberland River at Nashville, Tennessee. Oct. 1887 - Sept. 1931. Water Resources of Tennessee, 1925. Water Supply Papers (U. S. Geological Survey) Nos. 603, 623, 643, 663, 683, 698, 713.

3. Flint River near Woodbury, Georgia. Oct. 1900 - Sept. 1922. Water Supply Papers (U. S. Geological Survey) Nos. 197, 204, 242, 262, 282, 302, 322, 352, 382, 402, 432, 452, 472, 502, 522, 542.

4. Hiwassee River at Reliance, Tennessee. Oct. 1900 - Sept. 1932. Water Resources of Tennessee, 1925. Water Supply Papers (U. S. Geological Survey) Nos. 603, 623, 643, 663, 683, 698, 713, 728.

5. Ocmulgee River at Macon, Georgia. Jan. 1895 - Dec. 1910, files of U. S. Engineer Office, Savannah, Ga. Jan. 1911 - Dec. 1931, Daily River Stages, U. S. Weather Bureau; U. S. Engineer Department rating applied to obtain discharge.

6. Oconee River at Fraley's Ferry, Georgia.

Jan. 1904 - Dec. 1905 and Jan. - Dec. 1907, Water Supply Papers (U. S. Geological Survey) Nos. 197 and 242, respectively.

June - Dec. 1906 and Oct. 1909 - Sept. 1923, files of U. S. Engineer Office, Savannah, Ga.

Sept. 1923 - Dec. 1931, records of Southeastern Engineering Company, Birmingham, Alabama.

For the Annual Flood Method, supplementary data for 1906 and 1909 was

Sources of Flow Data (Continued).

obtained from Daily River Stages, U. S. Weather Bureau.

7. <u>Santee River at Ferguson, South Carolina</u>. Jan. 1908 - Dec. 1929. Water Supply Papers (U. S. Geological Survey) Nos. 542, 563, 582, 602, 622, 642, 662, 682, 697.

Note - Lake Murray Reservoir on Saluda River went into operation in 1930, thereby changing streamflow characteristics at Ferguson considerably. Therefore, the record used for this study was terminated in 1929.

8. <u>Savannah River at Augusta, Georgia</u>. Jan. 1876 - Dec. 1932. Records in files of U. S. Engineer Office, Savannah, Ga.

9. <u>Tennessee River at Chattanooga, Tennessee.</u> Oct. 1874 - Sept. 1932

Water Resources of Tennessee, 1925.

Water Supply Papers (U. S. Geological Survey) Nos. 603, 623, 643, 663, 683, 698, 713, 728.

10. <u>Yadkin River near Salisbury, North Carolina</u>. Jan. 1907 - Dec. 1909 and Jan. 1912 - Dec. 1927. Water Supply Papers (U. S. Geological Survey) Nos. 242, 262, 282, 302, 322, 352, 382, 402, 432, 452, 472, 502, 522, 542, 562, 582, 602, 622, 642, 662.

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